Food Sci. Biotechnol. Vol. 17, No. 1, pp. 212 ~ 215 (2008)

RESEARCH NOTE

Food Science and Biotechnology

Effect of Irradiation on the Color, Microbiological Quality, and Sensory Attributes of Frozen Ground Beef, Pork, and Chicken after 6 Months at –6°C

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Abstract The effect of gamma irradiation on the Hunter color values, microbiological quality, and sensory attributes of frozen ground beef, pork, and chicken was investigated. Fresh meat samples were purchased from local markets, packed and frozen in polyethylene bags, and irradiated at 5 kGy. The Hunter's L-values (lightness) were not significantly different in all the meat samples after irradiation, but the a-values (redness) were higher in the irradiated beef and pork than the non-irradiated ones. After 6 months of storage at –6°C, the L-values increased in all the meat samples and the a-value in chicken was lower in the irradiated sample than that of the control. The microbial counts decreased in all the samples right after irradiation, but the coliforms and yeasts & molds increased by 1-2 log cycles after 6 months even under frozen state. The overall acceptability of the meat was not affected by irradiation. Panelists had a higher likeness for the increased redness in irradiated beef. In general, only the color changes in meat as a result of irradiation were found to be species-dependent.

Keywords: ground meat, irradiation, color, microbiological quality, sensory attribute

Introduction

The presence of microorganisms, especially pathogens, in raw meat is of major concern in the meat industry because it poses risks to human health and compromises food safety. A number of outbreaks associated with consumption of undercooked meat have been reported worldwide (1-3). Due to this increasing food poisoning problem, the use of ionizing radiation as a means of improving the microbial safety of fresh meat has been legally approved in several countries. At present, at least 12 and 22 countries are using irradiation in raw red meat and poultry, respectively, to control parasites and foodborne pathogens and extend the shelf-life of the meat (4). Approved irradiation doses ranged from 2.0-8.0 kGy for raw, semi-prepared, and frozen beef and pork and 2.0-10.0 kGy for chicken meat (4).

While food irradiation can extend the shelf-life and enhance the food safety of the meat (5-7), it can also cause physical and chemical changes that could affect the sensory acceptability of the meat (8). Studies have shown that irradiation of fresh meat resulted in changes in color and formation of undesirable flavors and off-odors which leads to lower marketability of the product (9,10). To minimize these effects, however, it was recommended that raw meats be irradiated frozen and under vacuum-packaging condition (8,11,12).

There are ample available publications regarding the physical and microbiological changes in irradiated fresh meat. However, limited studies have been geared towards the comparison of these changes that occur in meat from different animal species, particularly in beef, pork, and chicken by irradiation and subsequent storage under frozen state. Thus, the objective of this study was to compare the changes in color, microbiological quality, and sensory attributes of frozen vacuum-packaged ground beef, pork, and chicken as affected by gamma irradiation during storage.

Materials and Methods

Sample preparation, irradiation, and storage Fresh ground beef and pork and chicken breast were purchased from local markets in Daegu, Korea. The chicken was deboned manually and ground using a laboratory blender, as described by Nam *et al.* (13). All ground meat samples were vacuum-packed in polyethylene bags and stored at –6°C overnight. The frozen meats were then irradiated in a Styrofoam box with dry ice at 5 kGy using a Cobalt-60 gamma irradiator at Korean Atomic Energy Research Institute (KAERI), Jeongeup, Korea. An absorbed dose was assured by a ceric/cerous dosimeter (Bruker Instruments, Rheinstetten, Germany). All samples were analyzed for color, microbiological quality, and sensory attributes immediately after irradiation and after 6 months of storage at –6°C.

Color measurement The Hunter's color L- (lightness), a- (redness), and b- (yellowness) values were determined using a colorimeter (CR-200; Minolta, Osaka, Japan). Measurements were taken at 3 random locations in the packaged surface of the frozen meat samples and the

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Received August 16, 2006; accepted September 11, 2007

averages were reported. A numerical total color difference (ΔE) was calculated from the Hunter values obtained. The L-, a-, and b-values of the standard plate are 97.66, −0.36, and 1.92, respectively.

Microbiological analysis All samples were analyzed for the total aerobic bacteria, yeasts & molds, and coliforms. Five g of meat were mixed with 45 mL sterile peptone water. Subsequent dilutions were prepared and plated on plate count agar (PCA) for the total aerobic bacteria, potato dextrose agar (PDA, acidified with tartaric acid) for yeasts & molds, and desoxycholate agar (DA) for coliforms. Microbial counting was performed 24 hr after incubation at 30 and 37°C for total aerobic bacteria and coliforms, respectively. Yeast & mold counts were determined 3 days after incubation at 30°C.

Sensory evaluation The meat samples were evaluated following defrosting for their color, aroma, off-odor, and overall acceptability by 10 trained panels. The panelists were instructed to record their rating using a 9-point hedonic scale (9=like extremely; 0=dislike extremely for color, aroma, and overall acceptability, and 9=extremely strong; 0=extremely weak for off-odor) (14).

Statistical analysis Results were analyzed statistically using the Statistical Analysis System for Windows V8. Analysis of variance and Duncan's multiple range test were employed.

Results and Discussion

Hunter's color The Hunter's color L-, a-, and b-values of ground beef, pork, and chicken were determined to compare the effects of irradiation on different meat species. Irradiation treatment at 5 kGy did not significantly affect the Hunter's lightness values in all the meat samples but the redness values were higher in irradiated beef and pork than the nonirradiated ones (Table 1). This result was in accordance with the findings of Nanke *et al.* (15), Nam *et al.* (16), and Kim *et al.* (17) in which the redness values of beef and pork were higher in irradiated samples than the control ones. Montgomery *et al.* (10) and Murano *et al.* (18) also reported that irradiated ground beef stored under vacuum resulted in a darker red color of the meat. The increased redness was attributed to the induced formation of oxymyoglobin-like pigment in pork and both oxymyoglobin- and metmyoglobin-like characteristics in beef as a result of irradiation (15). After 6 months of frozen storage, it was observed that unlike in the pork samples, the increased redness in irradiated beef was fairly stable. The L-values, on the other hand, became higher in all the meat samples and the a-value in irradiated chicken became lower compared to the control indicating that the meats became paler. Furthermore, the yellowness values in pork and chicken became significantly lower after irradiation. Millar *et al.* (9) reported that the L-values of beef irradiated at 5 kGy significantly increased with storage of 7 days at 4°C. In another study conducted by Lambert *et al.* (19), the color of fresh pork became paler throughout the 35-day storage at ambient and cold temperatures and the color changed from red to yellow. The discoloration of fresh meat was considered to be more dependent on myoglobin oxidation and oxygen consumption rate (20). It was stated that during storage of irradiated meat, the oxymyoglobin was converted to metmyoglobin resulting in an increased lightness of the meat color (9).

The overall changes in color (ΔE) showed that irradiation at 5 kGy slightly influenced the color of the meats. The magnitude of the color change in irradiated chicken as compared to untreated samples was higher than the total color changes observed in beef and pork and the change in ΔE between irradiated and non-irradiated beef was less than that in pork.

Microbiological quality The frozen ground meat samples contained relatively low initial microbial populations ranging from 10^1-10^4 CFU/g for the total aerobic bacteria and yeasts & molds (Table 2). The initial coliform counts were below the minimum detection level (10 CFU/g) in pork and beef samples but relatively high for chicken meat (1.4×10^2 CFU/g). After irradiation, there was a slight decrease (≤1 log) in the total plate and yeast & mold counts, and the coliforms in chicken were reduced to non-detectable level. The decrease in the microbial count of irradiated meat is expected since gamma irradiation is

Table 1. Hunter's color values of irradiated ground meats stored after 6 months at −6°C[1)]

Hunter's parameter[2)]	Storage period (month)	Beef		Pork		Chicken	
		0 kGy	5 kGy	0 kGy	5 kGy	0 kGy	5 kGy
L	0	36.33±1.11[ay]	36.81±1.12[ay]	51.35±2.00[ay]	53.02±1.49[ax]	49.31±2.06[ay]	47.30±1.67[ay]
	6	39.81±0.48[ax]	40.49±0.25[ax]	55.45±1.81[ax]	54.37±0.45[ax]	57.72±1.20[ax]	54.12±1.83[bx]
a	0	7.83±0.80[bx]	10.43±1.28[ax]	7.11±1.03[bx]	9.29±0.65[ax]	6.22±0.66[ay]	7.67±0.27[ax]
	6	7.78±0.25[bx]	9.98±0.17[ax]	7.98±0.76[ax]	8.67±0.56[ax]	7.80±0.11[ax]	5.71±1.30[by]
b	0	5.70±0.66[ax]	5.12±0.75[ax]	8.95±0.89[ax]	7.05±0.73[bx]	8.30±0.64[ax]	6.04±0.89[bx]
	6	3.32±0.35[ay]	4.00±0.54[ax]	10.07±0.73[ax]	6.69±0.31[bx]	9.27±0.89[ax]	7.46±1.46[ax]
ΔE	0	0.00	0.11	0.00	1.48	0.00	-1.86
	6	3.53	3.83	3.59	2.91	7.77	4.85

[1)ab]Means followed by the same letters within the row of each meat species are not significantly different ($p<0.05$); [xy]means followed by the same letters within the column per parameter are not significantly different ($p<0.05$).

[2)]L, Degree of lightness (white+100→0 black); a, degree of redness (red+100→−80 green); b, degree of yellowness (yellow (+70→−80 blue); ΔE, overall color difference ($\sqrt{\Delta L^2+\Delta a^2+\Delta b^2}$).

Table 2. Microbial count (CFU/g) of irradiated ground meats stored after 6 months at –6°C

Microorganism	Storage period (month)	Beef		Pork		Chicken	
		0 kGy	5 kGy	0 kGy	5 kGy	0 kGy	5 kGy
Total plate count	0	4.0×10^3	1.3×10^3	1.5×10^4	1.9×10^3	1.7×10^3	1.0×10^3
	6	3.9×10^3	9.6×10^2	7.3×10^3	3.1×10^3	3.2×10^3	4.9×10^2
Yeasts & molds	0	5.0×10^1	3.8×10^1	2.4×10^2	5.0×10^1	1.3×10^2	2.5×10^1
	6	1.7×10^3	2.7×10^2	2.6×10^3	3.4×10^2	1.5×10^3	9.0×10^1
Coliforms	0	<10[1)]	<10	<10	<10	1.4×10^2	<10
	6	1.8×10^1	<10	2.8×10^1	1.5×10^1	1.7×10^2	5.3×10^1

[1)]Non-detectable level.

known to reduce the number of bacteria in meat (21-23). However, the 1-log reduction in the total plate count of irradiated samples was relatively low which maybe attributed to the frozen state of the meat during irradiation. After 6 months at –6°C, the irradiated beef and chicken exhibited a 1-log reduction in the total plate count. On the contrary, the count slightly increased in irradiated pork but still lower compared to that of the control sample. In studying the microbial changes in irradiated fresh pork loins, Dogbevi *et al.* (22) noted that mesophilic bacteria were more resistant to gamma irradiation and gradually increased during storage at refrigeration temperature.

The yeasts & molds, on the other hand, increased by 1-2 logs in all the meat samples after 6 months indicating that they were able to proliferate during storage. Some molds are psychrotrophic and can grow at temperatures as low as –5 to –10°C (24). It was also observed that coliforms were able to survive at freezing temperature. The counts slightly increased in all the samples, except in irradiated beef, after 6 months. This suggests that although the beef and pork initially exhibited a non-detectable level of coliforms at month 0, the irradiation treatment did not totally eradicate the coliforms present in the meat which were then able to survive during cold storage.

Javanmard *et al.* (25) stated that irradiation in combination with frozen storage was more effective than treatment alone in decreasing the total aerobic and coliform counts in meat. However, the results of this study suggest that irradiation of meat at a dose of 5 kGy is not always lethal especially if the meat was irradiated under frozen state. The frozen condition of the meat may have provided protection to bacteria against radiation. Furthermore, the observed changes in bacterial counts could not be attributed to the species variation. Radiation-injured bacteria may have recuperated during prolong storage and were able to grow at low temperature (21). Nevertheless, the microbial counts in all the meat samples were still within the acceptable level even after 6 months.

Sensory attributes Sensory evaluation of beef showed a higher color score for irradiated sample than that of nonirradiated ones, indicating that the panelists had a higher likeness for the redder beef (Table 3). The color scores for pork and chicken were not affected by irradiation but became significantly higher in irradiated chicken after 6 months of storage. There was no significant difference for aroma between the irradiated and control samples. The panelists detected a slight off-odor in all the meat samples but no remarkable difference between treatments. This can be attributed to the vacuum packaging which minimizes oxidative changes responsible for the off-odor characteristics in irradiated meat (11,18). However, after 6 months of storage, all the meat samples exhibited a more pronounced off-odor. Previous studies have shown that the off-odor of irradiated raw meat was a combination of both irradiation off-odors and microbiological spoilage odors (19,26). The results of this study, however, demonstrated that the development of off-odor in ground meat was not due to

Table 3. Sensory quality[1)] of irradiated ground meats stored after 6 months at –6°C[2)]

Sensory parameter	Storage period (month)	Beef		Pork		Chicken	
		0 kGy	5 kGy	0 kGy	5 kGy	0 kGy	5 kGy
Color	0	4.5 ± 1.4^{bx}	6.3 ± 1.5^{ax}	4.5 ± 1.0^{ax}	4.8 ± 1.5^{ay}	4.0 ± 1.2^{ax}	5.2 ± 1.4^{ay}
	6	4.5 ± 2.0^{bx}	6.9 ± 1.6^{ax}	4.0 ± 1.2^{ax}	6.3 ± 1.2^{ax}	5.2 ± 1.4^{bx}	6.6 ± 1.1^{ax}
Aroma	0	3.2 ± 1.4^{ax}	4.3 ± 1.2^{ax}	4.1 ± 1.1^{ax}	4.1 ± 1.0^{ax}	4.3 ± 0.8^{ay}	5.1 ± 0.9^{ax}
	6	4.2 ± 1.6^{ax}	4.7 ± 1.6^{ax}	4.5 ± 1.4^{ax}	4.9 ± 1.2^{ax}	5.8 ± 1.2^{ax}	4.7 ± 1.5^{ax}
Off-odor	0	2.2 ± 1.4^{ay}	2.6 ± 1.5^{ay}	3.8 ± 1.4^{ay}	3.2 ± 1.3^{ay}	4.1 ± 0.6^{ay}	4.6 ± 1.4^{ax}
	6	6.1 ± 1.9^{ax}	5.4 ± 2.1^{ax}	5.4 ± 1.6^{ax}	5.4 ± 1.6^{ax}	5.3 ± 1.6^{ax}	5.6 ± 1.3^{ax}
Overall acceptability	0	4.1 ± 1.2^{ax}	5.2 ± 1.4^{ax}	3.6 ± 1.3^{ay}	3.5 ± 1.1^{ay}	4.1 ± 0.7^{ay}	4.3 ± 1.3^{ay}
	6	4.9 ± 1.4^{ax}	5.5 ± 1.6^{ax}	4.9 ± 1.0^{bx}	6.1 ± 1.4^{ax}	5.6 ± 1.3^{ax}	5.7 ± 1.2^{ax}

[1)]Sensory evaluation was conducted by 10 panelists using a 9-point hedonic scale (9-like extremely; 0-dislike extremely for color, aroma and overall acceptability, and 9-extremely strong; 0-extremely weak for off-odor).

[2)ab]Means followed by the same letters within the row of each meat species are not significantly different ($p<0.05$); [xy]means followed by the same letters within the column per parameter are not significantly different ($p<0.05$).

either irradiation treatment or microbiological spoilage since the samples exhibited relatively low microbial counts, but due to the prolong storage under freezing temperature. It may be possible that storage at $-6^{o}C$ for 6 months resulted in other changes affecting the meat composition, which needs a further investigation. Montgomery *et al.* (10) also found that storage time contributed to increased off-odor scores in non-irradiated beef trimmings.

Gamma irradiation showed no significant effects on the overall acceptability of the meat samples. Javanmard *et al.* (25) reported that irradiation at 5 kGy of chicken meat, followed by storage at $-18^{o}C$ for 9 months, did not affect the sensory properties of the product. As a whole, gamma irradiation treatment at 5 kGy did not cause any adverse effect on the sensory characteristics and overall acceptability of frozen ground meat, regardless of the species.

In conclusion, the results of this study demonstrated that the radiation-induced changes in meat color were species-dependent. Irradiation of vacuum-packaged beef resulted in a redder meat which was stable over time. The irradiated pork initially exhibited a darker red color but disappeared during storage. The magnitude of the color change between irradiated and control samples was highest in chicken meat. On the other hand, the changes observed in the microbiological quality and sensory properties of irradiated meat were found to be not species-dependent. Sensory acceptability of the irradiated meat was not adversely affected. However, irradiation at 5 kGy of ground meat under frozen state was not very effective in improving the microbial quality of the meat. A higher dose is required to decontaminate frozen ground meat. Further investigation into the effect of some higher doses and prolonged storage at freezing temperature on the microbiological quality and development of off-odor in meat is needed.

Acknowledgments

This work was supported in part by a grant from the Ministry of Science and Technology of Korea.

References

1. CDC. Multistate outbreak of *Escherichia coli* O157:H7 infections associated with eating ground beef-United States, June-July 2002. MMWR 51: 637-639 (2002)
2. FAO. *Escherichia coli* O157:H7 outbreak in Scotland in 1996/97. Available from: http://www.fao.org. Accessed Jan. 5, 2007.
3. Food HACCP. Foodborne outbreak information. Available from: http://www.foodhaccp.com/out2005. html. Jan. 5, 2007.
4. International Atomic Energy Agency. Clearance database. Available from: http://www.iaea.org/icgfi/data.htm. Accessed Dec. 4, 2006.
5. Spoto MH, Gallo CR, Alcarde SR, Gurgel MS, Blumer L, Walder JM, Domarco RE. Gamma irradiation in the control of pathogenic bacteria in refrigerated ground chicken meat. Sci. Agr. 57: 389-394 (2000)
6. Byun MW, Lee JW, Yook HS, Lee KH, Kim HY. Improvement of shelf-stability and processing properties of meat products by gamma irradiation. Radiat. Phys. Chem. 63: 361-364 (2002)
7. Thayer DW, Boyd G. Elimination of *Escherichia coli* O157:H7 in meats by gamma irradiation. Appl. Environ. Microb. 59: 1030-1034 (1993)
8. Dickson JS. Irradiation of fresh meat. pp. 418-432. In: Improving the Safety of Fresh Meat. Sofos JN (ed). Woodhead Publishing Ltd., Cornwall, England (2005)
9. Millar SJ, Moss BW, Stevenson MH. The effect of ionizing radiation on the colour of beef, pork, and lamb. Meat Sci. 55: 349-360 (2000)
10. Montgomery JL, Parrish FC, Olson DG, Dickson JS, Niebuhr S. Storage and packaging effects on sensory and color characteristics of ground beef. Meat Sci. 64: 357-363 (2003)
11. Ahn DU, Jo C, Du M, Olson DG, Nam KC. Quality characteristics of pork patties irradiated and stored in different packaging and storage conditions. Meat Sci. 56: 203-209 (2000)
12. Olson DG. Irradiation of food. Food Technol.-Chicago 52: 56-62 (1998)
13. Nam KC, Kim JH, Ahn DU, Lee SC. Effect of rice hull extract on lipid oxidation and volatiles of cooked turkey meat. Food Sci. Biotechnol. 13: 337-341 (2004)
14. Herbert A, Joel LS. Sensory Evaluation Practices. 2nd ed. Academic Press Inc., New York, NY, USA. pp. 68-75 (1993)
15. Nanke KE, Sebranek JG, Olson DG. Color characteristics of irradiated vacuum-packaged pork, beef, and turkey. J. Food Sci. 63: 1001-1006 (1998)
16. Nam KC, Ahn DU. Effects of irradiation on meat color- a review. Food Sci. Biotechnol. 12: 198-205 (2003)
17. Kim YH, Nam KC, Ahn DU. Color, oxidation-reduction potential, and gas production of irradiated meats from different animal species. J. Food Sci. 67: 1692-1695 (2002)
18. Murano PS, Murano EA, Olson DG. Irradiated ground beef: Sensory and quality changes during storage under various packaging conditions. J. Food Sci. 63: 548-551 (1998)
19. Lambert AD, Smith JP, Dodds KL. Physical, chemical, and sensory changes in irradiated fresh pork packaged in modified atmosphere. J. Food Sci. 57: 1294-1299 (1992)
20. O'Keefe M, Hood DE. Biochemical factors influencing metmyoglobin formation on beef from muscles of differing color stability. Meat Sci. 7: 209-228 (1982)
21. Lebepe S, Molins RA, Charoen SP, Farrar H, Skowronski RP. Changes in microflora and other characteristics of vacuum packaged pork loins irradiated at 3.0 kGy. J. Food Sci. 55: 918-924 (1990)
22. Dogbevi MK, Vachon C, Lacroix M. Physicochemical and microbiological changes in irradiated fresh pork loins. Meat Sci. 51: 349-354 (1999)
23. Kiss IF, Beczner J, Zachariev GY, Kovacs S. Irradiation of meat products, chicken and use of irradiated spices for sausages. Radiat. Phys. Chem. 36: 295-299 (1990)
24. Frazier WC, Westhoff DC. Food Microbiology. 4th ed. McGraw-Hill Book Co., Singapore, Singapore. pp. 21-22 (1988)
25. Javanmard M, Rokini N, Bokaie S, Shahhosseini G. Effects of gamma irradiation and frozen storage on microbial, chemical, and sensory quality of chicken meat in Iran. Food Control 17: 469-473 (2006)
26. Grant IR, Patterson MF. Effect of irradiation and modified atmosphere packaging on the microbiological and sensory quality of pork stored at refrigeration temperatures. Int. J. Food Sci. Tech. 26: 507-519 (1991)