



Effect of Gamma Irradiation on Shelf-life Extension and Sensory Characteristics of *Dak-galbi* (Marinated Diced Chicken) during Accelerated Storage

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Abstract

This study examined the effect of gamma irradiation on shelf-life extension and sensory characteristics of *dak-galbi*. Commercial *dak-galbi* sauce was gamma-irradiated at 0, 5, 10, 15, 20, 25, and 30 kGy. The *dak-galbi* sauce (200 g) was then added to diced chicken (800 g) for cooking, and the cooked *dak-galbi* samples in vacuum bags were stored at 35°C for 5 d. *Dak-galbi* samples were analyzed on d 0, 1, 2, 3, 4, and 5 for microbial analysis (plate count agar), thiobarbituric acid (TBARS) and volatile basic nitrogen (VBN) measurements, and on d 0 for sensory evaluation. On d 0, total bacterial populations were below detection limit after *dak-galbi* marinated with the gamma-irradiated (≥ 15 kGy) sauces were cooked, and the samples marinated with higher dose irradiated *dak-galbi* sauce had lower ($p < 0.05$) bacterial populations during storage. TBARS values of the *dak-galbi* samples marinated with non-irradiated sauce were not different ($p \geq 0.05$) with those marinated with irradiated sauces on d 0, and the TBARS values increased ($p < 0.05$) during storage at 35°C, regardless of irradiation dose. In the VBN analysis, there was no difference ($p \geq 0.05$) in VBN values among irradiation doses on d 0, but VBN values decreased ($p < 0.05$) as irradiation dose increased during storage. Moreover, there were no significant differences ($p \geq 0.05$) in sensory characteristics among irradiation doses. These results indicate that use of gamma irradiation on *dak-galbi* sauce may be useful in shelf-life extension without compromising the sensory characteristics of *dak-galbi*.

Key words: irradiation, chicken, *dak-galbi*, sauce

Introduction

Dak-galbi is a popular South Korean dish generally prepared by stir-frying diced chicken after marination in a *gochujang* (chili pepper paste) based sauce, and sliced cabbage, sweet potato, scallions, onions and *tteok* (rice cake) together on a hot plate. *Dak-galbi* sauce usually composed of soy sauce, garlic, pepper, corn syrup, red pepper paste, sugar, and ginger. Because *dak-galbi* sauce should be prepared without heating, non-thermal treatment to *dak-galbi* sauce may be useful in decrease of

pathogenic and food spoilage bacteria, resulting in extended shelf-life and ensured food safety of *dak-galbi* sauce.

Gamma irradiation has been suggested as the non-thermal method for destroying pathogenic and spoilage microorganisms in the final products without compromising the nutritional properties and sensory characteristics of foods (Ahn *et al.*, 2004; WHO, 1999). This technology is used as a method of food preservation in more than 50 countries, including Belgium, Canada, France, South Korea, India, United States, Netherlands, and others (Turgis *et al.*, 2008). Furthermore, use of irradiation on foods was adopted by international organizations such as World Health Organization, International Atomic Energy Agency, and World Trade Organization because of its wholesomeness and economic benefits (WHO, 1999). The status

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report by Kume *et al.* (2009b) showed that quantity of irradiated foods in the world in 2005 was 405,000 ton (\$ 17 billion) and comprised 186,000 ton (46%) for disinfection of spices and dry vegetables, 82,000 ton (20%) for sprout inhibition of garlic and potato, and 17,000 ton (4%) of other food items. In addition, the economic scale was \$ 11 billion in the American region, \$ 3 billion in Asia and Oceania, \$ 1.9 billion in Africa, and \$ 529 billion in Africa and Ukraine, and \$ 529 billion in the EU (Kume *et al.*, 2009a).

Many studies showed that irradiation increased the shelf-life of beef and pork under different conditions such as packaging methods and irradiation temperatures (Kim *et al.*, 1998; Ko and Whang, 2002; Lee *et al.*, 2004; Robert and Weese, 1998; Waje *et al.*, 2008; Whang, 2002), and high dose (50 kGy) of gamma irradiation improved storage stability of marinated pork ribs during accelerated storage at 35°C (Lee *et al.*, 2006). Jo *et al.* (2003) showed that 10-kGy irradiated *bulgogi* (marinated barbecued beef) sauce containing soy sauce, sesame oil, garlic, onion and other seasonings was not spoiled up to 4 wk at 20°C. Lee *et al.* (2001) also presented that a irradiation dose of 7 kGy improved storage stability of *bulgogi* sauce for 6 wk at 20°C. Like the *bulgogi* sauce, *dak-galbi* sauce may have high risk of possible contamination of pathogens and spoilage bacteria because the sauce is prepared with various food ingredients, which may introduce bacterial contamination sources into *dak-galbi* sauce. Therefore, the objective of this study was to examine the effect of gamma irradiation on shelf-life extension and sensory characteristics of *dak-galbi*.

Materials and Methods

Sample preparation and gamma irradiation

Commercial *dak-galbi* sauce (water: 25%, soy sauce: 5%, garlic: 5%, pepper: 0.5%, corn syrup: 10%, red pepper paste: 45%, sugar: 5%, ginger: 4.5%) was purchased from a local *dak-galbi* franchise restaurant in Jeongeup-si, Jeollabuk-do, South Korea. The 1 kg portions of the samples were gamma-irradiated at 0, 5, 10, 15, 20, 25, and 30 kGy. The *dak-galbi* sauce (200 g) and water (100 mL) were added to diced chicken (800 g) on an electronic pan (NU-VUE-3 Cooker, Menominee, MI. USA) for 12-min stirfrying, and the cooked samples were cooled at room temperature. The *dak-galbi* samples were then vacuum-packaged in vacuum bags (aluminum-laminated low density polyethylene; melting point: 120°C, density: 0.92 g/cm³; Al-LDPE, Sunkung Co. Ltd., Seoul, South Korea),

and stored under an accelerated condition (35°C) for 5 d. *Dak-galbi* samples were analyzed on d 0, 1, 2, 3, 4, and 5 for microbial analysis, thiobarbituric acid (TBARS) and volatile basic nitrogen (VBN) measurement, and on d 0 for sensory evaluation.

Gamma irradiation was conducted using a cobalt-60 irradiator (IR-221; MDS Nordion International Co. Ltd., Ottawa, Ontario, Canada) in Advanced Radiation Technology Institute of Korea Atomic Energy Research Institute (Jeongeup-si, Jeollabuk-do, South Korea). The source strength was approximately 300 kCi with a dose rate of 10 kGy/h. Dosimetry was applied using 5-mm diameter alanine dosimeters (Bruker Instruments, Rheinstetten, Germany).

Microbial analysis

To enumerate total bacterial populations in *dak-galbi* during storage, the 10 g portions of *dak-galbi* samples were aseptically transferred into sterile bags (20×25 cm; Sunkyung Co., Seoul, South Korea) containing 90 mL of 0.1% peptone water followed by pummeling samples in a stomacher (Model 400, Tekmar Co., Los Angeles, CA, USA) for 2 min. The homogenates were serially diluted with 0.1% peptone water. The diluents (1 mL) were then placed on petri plates, and 20 mL of plate count agar (PCA; Difco, Becton Dickinson, Sparks, MD, USA) was poured over the diluents. After the media became solid, plates were incubated at 37°C for 48 h and colonies on the plates were manually counted.

TBARS measurement

In order to measure lipid oxidation of *dak-galbi*, TBARS values of *dak-galbi* samples was measured. The *dak-galbi* sample (3 g) was placed in a 50-mL centrifuge tube, and homogenized with 10 mL of 10% TCA (trichloroacetic acid in 2 M phosphoric acid) and 17 mL of distilled water by a homogenizer (DIAX 900, Heidolph Co., Ltd., Schwabach, Germany). The homogenates were then centrifuged at 4°C for 15 min at 2,500 rpm, and supernatants were filtered through Whatman paper (No. 4). The 2 mL of the homogenate was mixed with 2 mL of 20 mM 2-thiobarbituric acid (15% in trichloroacetic acid solution), and the mixture was heated in boiling water (100°C) for 20 min, followed by cooling in ice water for 5 min. Absorbance of the mixtures were measured at 532 nm using a spectrophotometer (UV 1600 PC, Shimadzu, Tokyo, Japan), and it was reported as µg malondialdehyde/g.

VBN measurement

VBN values were determined according to the method recommended by Miwa and Iida (1973). Three g of samples were mixed with 10 mL of 10% TCA for 1 min, and additional 17 mL of 10% TCA were added to the mixture followed by filtering through Whatman paper (No. 4). One mL of filtrate was placed in outer space of Conway unit, and 1 mL of 0.01 N H₃BO₃ and 50 µL of Conway reagent (0.066% methyl red in ethanol : 0.066% bromocresol green in ethanol = 1:1) were added in inner space. The Conway unit was sealed immediately after adding 1 mL of saturated K₂CO₃ to the outer space. The sealed Conway unit was shaken slowly and incubated at 37°C for 120 min. The 0.02 N H₂SO₄ was added to the inner space for a titration. The VBN was then calculated using the following equation.

$$\text{VBN mg\% (mg/100 g sample)} \\ = (((a-b) \times f \times 28.014) / S) \times 100$$

Where *S* is the sample weight in grams, *a* is the volume (mL) of added H₂SO₄ in blank, and *f* is the standard factor of H₂SO₄.

Sensory evaluation

Sensory evaluation of *dak-galbi* was conducted by 10 panels who were trained according to the method described by Civille and Szczesniak (1973). Color, appearance, flavor, taste, texture, off-odor, and overall acceptance of the samples were evaluated using a 7 point descriptive scale where 1 = extremely dislike or extremely weak to 7 = extremely like or extremely strong.

Statistical analysis

Samples were analyzed in triplicate for microbiological analysis, duplicate for TBARS and VBN, and one sample

per panel for sensory evaluation. All data (total bacterial populations, TBARS, VBN, and sensory evaluation) were analyzed by the generalized linear model procedures of the SAS[®] version 9.2 (SAS Institute, Cary, NC, USA). All least squares mean comparisons were performed by the Tukey's multiple comparison, and a *p*-value of 0.05 was used for statistical significance.

Results and Discussion

Total bacterial population of *dak-galbi* sauce was 6.2 log CFU/g before irradiation, but the populations in the sauce decreased to below detection limit (1 log CFU/g) after irradiation at 30 kGy (data not shown in a tabular form). After marination of *dak-galbi* with the sauce and cooking, initial bacterial populations of cooked *dak-galbi* marinated with non-irradiated sauce were 2.6 log CFU/g, but the populations decreased below detection limit when *dak-galbi* samples were marinated with the sauce irradiated at more than 15 kGy (Table 1). Since *dak-galbi* sauce contains various spices which may contain highly irradiation resistant spores and high dose irradiation may lead to adverse effects of sensory characteristics on chicken, irradiation was applied to *dak-galbi* sauce.

Although total bacterial populations in *dak-galbi* samples were below detection limit on d 0, the bacterial cell counts in the samples were significantly (*p*<0.05) increased during storage. This result indicates that injured cells from irradiation may be rapidly recovered during storage. Since injured cells may become more resistant to various stresses such as acid and heat compared to normal cells when they were recovered (Calicioglu *et al.*, 2002; Yoon *et al.*, 2006), presence of injured cells in *dak-galbi* sauce should not be overlooked (Doyle *et al.*, 2001; Scott *et al.*, 2005).

Table 1. Total bacterial populations (log CFU/g) recovered with plate count agar in cooked *dak-galbi* after marination with gamma-irradiated sauces during accelerated storage for 5 d at 35°C

Irradiation doses (kGy)	Storage (d)					
	0	1	2	3	4	5
0	2.6±0.4 ^{Ac}	5.3±0.3 ^{Ab}	6.7±0.4 ^{Aa}	-	-	-
5	2.1±0.4 ^{Ac}	4.2±0.4 ^{Bb}	6.4±0.3 ^{Aa}	-	-	-
10	2.3±0.2 ^{Ac}	4.7±0.4 ^{Ab}	6.2±0.3 ^{Aa}	-	-	-
15	<1.0±0.0 ^{Bd}	3.4±0.3 ^{BCc}	5.3±0.1 ^{Bb}	7.6±0.4 ^{Aa}	-	-
20	<1.0±0.0 ^{Bd}	3.2±0.3 ^{Cc}	4.4±0.2 ^{BCb}	6.6±0.2 ^{Ba}	-	-
25	<1.0±0.0 ^{Be}	2.8±0.3 ^{Cd}	3.8±0.2 ^{CDc}	5.5±0.4 ^{Cb}	7.3±0.2 ^{Aa}	-
30	<1.0±0.0 ^{Be}	<1.0±0.0 ^{De}	3.3±0.1 ^{Dd}	3.9±0.3 ^{Dc}	5.5±0.3 ^{Bb}	6.3±0.4 ^{Aa}

Bar indicates no determination of bacterial populations because of spoilage.

^{A-D}: Mean ± standard deviation within a column with different superscripts are significantly different (*p*<0.05).

^{a-c}: Mean ± standard deviation within a row with different superscripts are significantly different (*p*<0.05).

The samples marinated with sauces irradiated at 0-10 kGy were completely spoiled after 3 d, and bacterial populations in *dak-galbi* lowered ($p<0.05$) as irradiation dose used to *dak-galbi* sauce increased (Table 1). In addition, many other studies also showed that irradiation increased the shelf-life of foods (Kim *et al.*, 1998; Ko and Whang, 2002; Lee *et al.*, 2004; Robert and Weese, 1998; Waje *et al.*, 2008; Whang, 2002), and the high levels of bacterial populations in *dak-galbi* sauce may be introduced from raw materials including soy sauce, red pepper paste, sugar, and spices, resulting in shortening the shelf-life of the sauce and growth of pathogens (Jo *et al.*, 2003). Thus, use of irradiation in *dak-galbi* sauce may be useful in reduction of spoilage bacterial populations, resulting in increased shelf-life of *dak-galbi*.

The TBARS values (1.69 $\mu\text{g/g}$) of the *dak-galbi* samples marinated with non-irradiated sauce were not different ($p\geq 0.05$) with those (1.72-2.01 $\mu\text{g/g}$) marinated with irradiated sauces on d 0, but the TBARS values significantly ($p<0.05$) increased during accelerated storage at 35°C, regardless of irradiation dose (Table 2). This lipid oxidation may be induced by hydroxyl radicals generated

by ionizing irradiation on meat and poultry products, and the lipid oxidation may adversely affect color, flavor, texture and nutritive value of foods (Smith *et al.*, 1960). However, the result from our study showed that there was no obvious gamma irradiation effect on lipid oxidation of *dak-galbi* because irradiation was conducted on *dak-galbi* sauce rather than *dak-galbi*. Taken together, irradiation on *dak-galbi* sauce should be more efficient method than irradiation on *dak-galbi* to prevent lipid oxidation as well as growth of spoilage bacteria.

In the VBN analysis, there was no significant differences ($p\geq 0.05$) in VBN values among irradiation doses on d 0, but VBN values decreased ($p<0.05$) as irradiation dose increased during storage and VBN values in *dak-galbi* generally increased ($p<0.05$) during storage (Table 3). These results indicate that irradiation on *dak-galbi* sauce may be involved in shelf-life improvement of *dak-galbi* during storage. The studies by Naik *et al.* (1994) and Kim *et al.* (2004) also showed that irradiation is effective to lower VBN values in meat products because irradiation decreases levels of spoilage bacteria on samples, resulting lower VBN values than those of non-irra-

Table 2. Thiobarbituric acid (TBARS) values (μg malondialdehyde/g) in cooked *dak-galbi* after marination with gamma-irradiated sauces during accelerated storage for 5 d at 35°C

Irradiation dose (kGy)	Storage (d)					
	0	1	2	3	4	5
0	1.69±0.08 ^{Aa}	1.65±0.04 ^{Aa}	-	-	-	-
5	1.72±0.09 ^{Aa}	1.83±0.09 ^{Aa}	-	-	-	-
10	1.78±0.11 ^{Aa}	1.76±0.04 ^{Aa}	-	-	-	-
15	1.80±0.06 ^{Aa}	1.94±0.03 ^{Aa}	2.09±0.08 ^{Ba}	-	-	-
20	1.85±0.02 ^{Ab}	1.98±0.09 ^{Ab}	2.09±0.11 ^{Bb}	3.25±0.01 ^{Aa}	-	-
25	1.95±0.06 ^{Ab}	2.03±0.14 ^{Ab}	2.36±0.28 ^{ABb}	2.95±0.10 ^{Aa}	3.05±0.09 ^{Ba}	-
30	2.01±0.10 ^{Ad}	2.12±0.13 ^{Ad}	2.78±0.16 ^{Ac}	3.16±0.12 ^{Ac}	3.74±0.14 ^{Ab}	4.44±0.06 ^{Aa}

¹⁾Bar indicates no determination of bacterial populations because of spoilage.

^{A-B}Mean ± SD within a column with different superscripts are significantly different ($p<0.05$).

^{a-c}Mean ± SD within a row with different superscripts are significantly different ($p<0.05$).

Table 3. Volatile basic nitrogen (VBN) values (mg %) in cooked *dak-galbi* after marination with gamma-irradiated sauces during accelerated storage for 5 d at 35°C

Irradiation dose (kGy)	Storage (d)					
	0	1	2	3	4	5
0	10.35±4.03 ^{Ab}	40.10±1.34 ^{Aa}	- ¹⁾	-	-	-
5	10.80±1.91 ^{Aa}	22.63±1.38 ^{Ba}	-	-	-	-
10	11.65±1.41 ^{Aa}	21.29±0.80 ^{Ba}	-	-	-	-
15	9.98±1.17 ^{Ab}	20.64±0.41 ^{Bb}	74.16±0.88 ^{Aa}	-	-	-
20	11.63±0.60 ^{Ab}	17.71±2.10 ^{Bb}	66.43±8.49 ^{Aa}	74.12±1.86 ^{Aa}	-	-
25	11.20±0.49 ^{Ad}	17.11±1.18 ^{Bd}	42.50±2.99 ^{Bc}	68.53±2.16 ^{Ab}	90.93±5.35 ^{Aa}	-
30	10.68±0.39 ^{Ad}	10.09±1.15 ^{Bc}	33.31±1.22 ^{Bb}	41.21±1.34 ^{Bb}	87.03±8.04 ^{Aa}	91.50±3.11 ^{Aa}

¹⁾Bar indicates no determination of bacterial populations because of spoilage.

^{A-B}Mean ± SD within a column with different superscripts are significantly different ($p<0.05$).

^{a-d}Mean ± SD within a row with different superscripts are significantly different ($p<0.05$).

Table 4. Sensory characteristics of cooked *dak-galbi* after marination with gamma-irradiated sauces on d 0

Irradiation dose (kGy)	Sensory characteristics					
	Appearance	Taste	Flavor	Texture	Off-flavor	Overall acceptability
0	6.3±0.2 ^a	6.1±0.3 ^a	6.2±0.2 ^a	6.4±0.1 ^a	1.1±0.1 ^a	6.4±0.3 ^a
5	6.5±0.3 ^a	6.0±0.3 ^a	6.2±0.2 ^a	6.4±0.1 ^a	1.1±0.1 ^a	6.4±0.3 ^a
10	6.5±0.3 ^a	6.0±0.3 ^a	6.3±0.1 ^a	6.4±0.1 ^a	1.1±0.2 ^a	6.4±0.3 ^a
15	6.2±0.1 ^a	5.9±0.4 ^a	6.3±0.2 ^a	6.4±0.2 ^a	1.1±0.1 ^a	6.5±0.3 ^a
20	6.3±0.2 ^a	5.9±0.4 ^a	6.2±0.1 ^a	6.4±0.1 ^a	1.1±0.2 ^a	6.5±0.4 ^a
25	6.3±0.3 ^a	5.8±0.2 ^a	6.2±0.1 ^a	6.3±0.1 ^a	1.2±0.1 ^a	6.5±0.4 ^a
30	6.2±0.4 ^a	5.7±0.3 ^a	6.2±0.2 ^a	6.3±0.2 ^a	1.1±0.1 ^a	6.4±0.3 ^a

^aMean ± standard deviation within a column with same superscripts are not significantly different ($p \geq 0.05$)

diated samples (Choi *et al.*, 2002).

Effect of gamma irradiation on sensory characteristics was evaluated only for d 0 because of safety concern to panels. The results of sensory evaluation showed that there were no significant differences ($p \geq 0.05$) in sensory characteristics among irradiation doses, indicating that gamma irradiation on *dak-galbi* sauce did not influence sensory characteristics of cooked *dak-galbi* (Table 4). This result agreed with results from the study of Jo *et al.* (2003) showing that irradiation to *bulgogi* sauce did not affect sensory of *bulgogi*.

In conclusion, use of gamma-irradiation on *dak-galbi* sauce may be useful in extension of shelf-life without compromising the sensory characteristics of *dak-galbi*.

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