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Effect of Gamma-Irradiated Red Pepper Powder on Physicochemical Properties of *Kakdugi*, a Korean Traditional Radish Kimchi

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Abstract

Physicochemical properties and sensory characteristics of kakdugi prepared with red pepper powder gamma-irradiated up to 7 kGy were determined during fermentation at 5°C. The overall fermentation patterns between kakdugies with irradiated and nonirradiated red pepper powder were similar. Kakdugi prepared with irradiated red pepper powder required one week longer time for optimal ripening compared to the kakdugi control. Irradiated red pepper powder did not affect the hardness and fracturability of kakdugi during fermentation. Kakdugi prepared with irradiated red pepper powder maintained a redder color than the kakdugi control. No significant differences were observed in taste, odor, texture, and overall acceptability ($p < 0.05$) except for color. It can be concluded that irradiation of red pepper powder, up to 7 kGy, did not affect the quality of kakdugi with regard to physicochemical and sensory characteristics during fermentation. Moreover, irradiated red pepper powder was better for maintaining the red color and delaying optimum ripening time of kakdugi fermentation.

Key words: gamma-irradiated red pepper powder, kakdugi, physicochemical property, sensory evaluation

INTRODUCTION

Kakdugi is a type of Korean traditional kimchi including radish pieces and red pepper powder as the primary ingredients. The most important organoleptic attributes of kakdugi are red color and pungent taste, which are mainly derived from red pepper powder (1). Although fresh radish has a pungent principle, the pungent flavor from well-fermented radish cubes in kakdugi has been reported as not detectable by both sensory test and instrumental analysis, because the low pH produced during fermentation causes the decomposition of the pungent radish components (2,3). Many beneficial properties of kimchi have been reported including antimutation and anticancer effects (4), hypolipidemic effect (5), antioxidation and antiaging (6), and activation of detoxifying enzymes (7). Nowadays, kimchi is recognized worldwide as a nutritious and wholesome food.

Recently, consumers have become interested in the wholesomeness of foods as well as their functional properties. In line with this, sanitation is a very important aspect of safety. For the sanitation of spices, including red pepper powder, fumigation has commonly been used. Despite its good effectiveness, many countries restrict chemical fumigation because of possible toxic residues and occupational health hazards for workers (8). Furthermore, ethylene oxide treatment of spices has been reported to cause deterioration in the sensory attributes (9-11). Gamma-irradiation now substitutes for fumigation; and irradiation is more effective than ethylene oxide in controlling microbial contamination of spices (12,13). Further, gamma-irradiation does not form chemical residues or induce an adverse effect on spice quality.

Studies concerning chemical, microbiological, and toxicological aspects of irradiated spices have been carried out (14). However, information on quality characteristics of foods prepared with irradiated red pepper powder is still limited. In Korea, hot red pepper powder is an essential spice for cooking as well as manufacture of kimchi, and its irradiation has been authorized up to 10 kGy.

In this study, kakdugi was prepared with gamma-irradiated red pepper powder and used to evaluate the effects of irradiated red pepper powder on its physicochemical and sensory properties during fermentation.

MATERIALS AND METHODS

Gamma-irradiation

Red pepper (*Capsicum annum* L.) powder processed in 2003 was purchased from an Agricultural Union market in Daejon, Korea. The red pepper powder was vacuum-packaged in polyethylene/polypropylene bags (2

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mL $O_2/m^2/24$ h at 0°C 20 cm×30 cm Sunkyung Co., Ltd., Seoul, Korea) and irradiated in a cobalt-60 gamma irradiator (Point Source, AECL, IR-79; Nordion, Canada) at doses of 3, 5, and 7 kGy. The source strength was approximately 100 kCi with a dose rate of 70 Gy/min at 15±0.5°C, and the actual doses were within ±2% of the target dose. The absorbed dose was measured with both free-radical and ceric/cerous dosimeters (15). Non-irradiated red peeper powder vacuum-packaged in the same type bag, was also prepared as a control.

Kakdugi preparation

Kakdugi preparation was followed the method of Kim and Kim (16) with some modification. Radish root was peeled and cut into 2×2×2 cm cubes, and then mixed well with condiments. The ingredients for the condiments were 4.0 g irradiated red pepper powder, 3.0 g garlic, 6.68 g green onion, 4.0 g salt, 4.6 g sucrose, 1.0 g ginger, and 20 mL water per 200 g of the radish. Kakdugi 200 g was put into glass jars and stored at 5°C for 70 days (Incubator, LTI-1000SD, Eyela; Rikakikai Co., Ltd., Tokyo, Japan). For chemical analyses, kakdugi was homogenized and filtered (No. 2; Whatman, Kent, England), and 10-fold diluted solutions were used.

Determination of pH, acidity and reducing sugar

The pH was determined with a pH meter (Model 520A Orion Boston, MA, USA). The acidity was measured by titration of a 10-mL filtrate with 0.1 N NaOH and expressed as the amount of lactic acid in kakdugi (17). Reducing sugar was measured by absorbance at 550 nm with a spectrophotometer (Model 80-2088-64; Pharmacia Biotech. Co., Cambridge, England) using a 3,5-dinitrosalicylic acid (DNS) method, and expressed as glucose amount in kakdugi (18).

Enumeration of lactic acid bacteria and yeast in kakdugi

Kakdugi liquid was serially diluted 10-fold with 0.85% sterilized saline. Each diluted solution was transferred into Lactobacillus MRS agar (Difco Lab., Detroit, MI, USA) for lactic acid bacteria and into PDA agar (Difco Lab.) for yeast growth by the pour-plate method. After incubation at 38°C for 48 h, total lactic acid bacteria and total yeast counts were determined.

Evaluation of surface and extractable color

The surface color of kakdugi was measured as Hunter L* (lightness), a* (±, redness/greenness), and b* (±, yellowness/blueness) values with a colorimeter (ND-1001 DP; Nippon Denshoku Co. Ltd., Osaka, Japan). Extractable color of kakdugi was evaluated by the American Spice Trade Association (19) method. Each 0.1 g of freeze-dried kakdugi powder was weighed into a 100-mL volumetric flask and brought to volume with acetone. The mixture was shaken, and stored in the dark for 16 h at room temperature. Spectrophotometric absorbance was measured at 460 nm and the ASTA units were obtained, a correction factor was calculated from the absorbance of a standard solution of potassium dichromate and ammonium and cobalt sulfate (20).

$$\text{ASTA unit} = \frac{\text{absorbance of acetone extract} \times 16.4 \times \text{a correction factor}}{\text{weight (g) of freeze-dried kakdugi powder}}$$

Analysis of texture

Texture of kakdugi (2×2×2 cm) was measured by Texture Profile Analysis (TPA) using a Texture Analyzer (TA XT2; Stable Micro Systems Co., London, England). Operating conditions of the texture analyzer were as shown in Table 1. All analyses were repeated 10 to 14 times.

Sensory evaluation

Sensory characteristics of kakdugi was evaluated by 10 trained panel members using a rating method based on color, aroma, taste, texture and overall acceptability. The panelists (all in members of the Dept. of Food Sci. and Nutrition, Chungnam National Univ.) had at least 2 years experience in kimchi processing research projects. An unstructured scale (10 cm) was provided to the panelists and the intensity of each sensory attributes were marked on the line scale. After measuring the marked position, the length was transformed into a 10-point scale (1-weakest, 5-mild, and 10-strongest). Steamed rice was given as a delivery item during each test. The sensory analysis was conducted in a sensory testing room with partitioned booths (21).

Statistical analysis

Two-way analysis of variance (ANOVA) was used to determine the effect of irradiated red pepper powder on the physicochemical and sensory quality changes of kakdugi by SAS software (SAS Institute Inc., Cary, NC, USA). Results of treatments and fermentation time were analyzed with Duncan's multiple range test post-hoc

Table 1. Analytical conditions of texture analyzer for texture profile analysis

Probe	Φ 5 mm
Force threshold	20 g
Contact area	18.75 mm^2
Contact force	5.0 g
Pre-test speed	5.0 mm/s
Post-test speed	5.0 mm/s
Test speed	5.0 mm/s
Strain	75%
Time	2.0 s
Trigger type	Auto 10 g

ANOVA of SAS (22).

RESULTS AND DISCUSSION

Acidity and pH

Changing patterns of pH and acidity during fermentation of kakdugi prepared with red pepper powder gamma-irradiated at doses of 0, 3, 5, or 7 kGy are shown in Fig. 1. For the control kakdugi, prepared with non-irradiated red pepper powder, pH and total acidity were 5.61 and 0.19%, respectively, at the start of fermentation, and then pH decreased to 4.08 and the acidity reached 0.58% after 21 days of fermentation at 5°C, whereas kakdugi with gamma-irradiated red pepper powder showed higher pH values (4.11~4.35) and lower acidities (0.41~0.52%) than the control kakdugi at 21 days of fermentation. An optimal ripening time for the best edible quality of kimchi is reported to be the time required for reaching 0.6% acidity (23). Based on the acidity (0.6%), the optimum fermentation time for kakdugi with irradiated red pepper powder was 28 days at 5°C, while that of the control kakdugi was 21 days. Thus, irradiated red pepper powder might delay the initial fermentation of kakdugi, although the extent of delay was not exactly in accordance with the irradiation dose level. This observation could be explained by the remarkably decreased microbial counts, especially for lactic acid bacteria and yeast, of gamma-irradiated red pepper powder compared to the non-irradiated control (Table 2). However, the acidity of kakdugi with irradiated red pepper powder increased more rapidly after 28 days of fermentation, and reached acidities of 0.85~0.90%, showing similar acidity to the control kakdugi (0.86%) at 70 days of fermentation. In addition, saltiness of kakdugi with irradiated red pepper powder and non-irradiated control stayed in the range of 0.8~1.3% during the entire fermentation period.

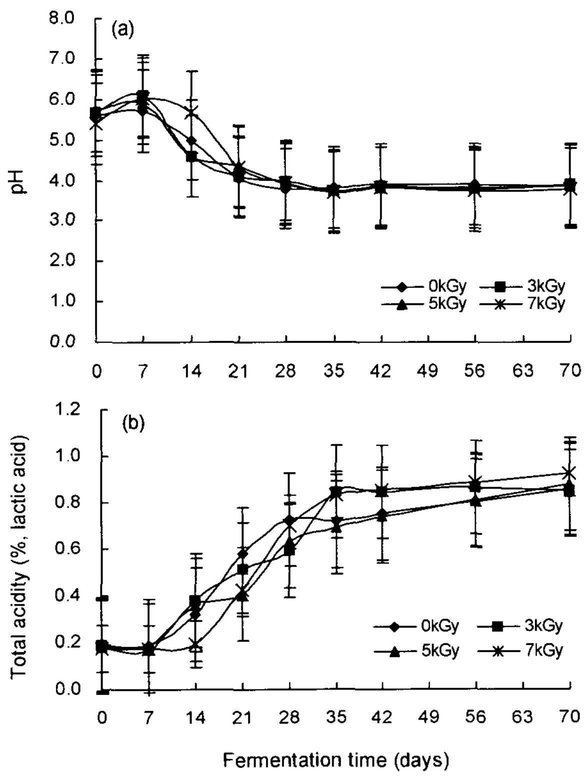

Fig. 1. Changes in pH (a) and acidity (b) of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

Table 2. Changes in total lactic acid bacteria and total yeast counts of irradiated red pepper powder and non-irradiated control[1,2] (Unit: log CFU/g)

Treatment (kGy)	Lactic acid bacteria	Yeast
0	6.79±0.21[a]	4.88±0.24[a]
3	5.89±0.19[b]	4.71±0.05[a]
5	5.23±0.20[c]	4.27±0.17[b]
7	4.08±0.11[d]	nd[3]

[1]Values are means of triplicates ± standard deviation.
[2]Means in the same column with different letters are significantly different ($p<0.05$).
[3]Not detected.

Reducing sugar

The trend for reducing sugar changes in kakdugi with irradiated red pepper powder was similar to that of control kakdugi, as depicted in Fig. 2. The amount of reducing sugar in control kakdugi (28.29 mg/mL) after 21 days of fermentation was a little higher than those of kakdugi samples with irradiated red pepper powder (20.99~27.09 mg/mL). These observations corresponded with the results of pH and acidity (Fig. 1). The amount of reducing sugar in kakdugi with gamma-irradiated red pepper powder, except for 7 kGy, decreased rapidly after 21 days of fermentation, and reached 20.99~21.28 mg/mL after 35 days of fermentation, whereas the reducing sugar amount of control kakdugi also decreased after 21

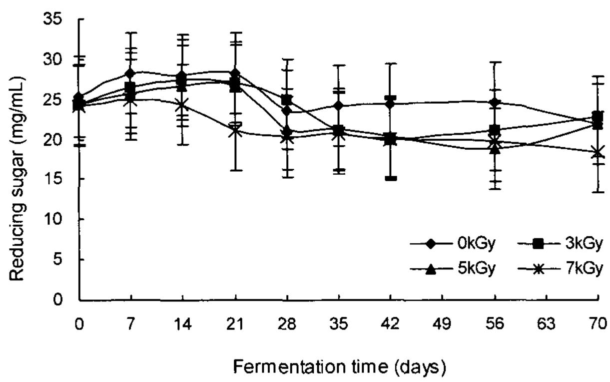

Fig. 2. Changes in reducing sugar amount of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

days and reached 23.67 mg/mL after 28 days of fermentation, but the amount remained stable until 56 days of fermentation. Thus, the amount of reducing sugar in control kakdugi was higher than those of kakdugi with gamma-irradiated red pepper powder between 35 and 56 days of fermentation. Also, the patterns of soluble solid content (data not shown) of kakdugi filtrate from control and gamma-irradiated red pepper powder during fermentation were similar to those of reducing sugar amount.

Lactic acid bacteria and yeast

Red pepper and red pepper powder are subject to microbial contamination, which could adversely affect kimchi fermentation; thus, the microbial count of red pepper powder itself was determined. The moisture contents of control and the irradiated red pepper powders were 13.51~15.68% (24). The total lactic acid bacteria count and total yeast count in non-irradiated red pepper powder were 6.79 (log CFU/g) and 4.88 (log CFU/g), respectively, and the counts decreased as irradiation dose increased. The total lactic acid bacteria counts of control were significantly reduced by 2 log values at the dose of 7 kGy ($p<0.05$), and yeasts were not detected at 7 kGy (Table 2). After kakdugi preparation with the above red pepper powders, we determined the changes of microbial counts of kakdugi during fermentation. Total lactic acid bacteria counts of kakdugi with non-irradiated and gamma-irradiated red pepper powder are shown in Fig. 3. In control kakdugi, total lactic acid bacteria counts reached the maximum with 8.6 (log CFU/mL) at 21 days of fermentation, maintained the counts up to 28 days, and then decreased to 6.9 (log CFU/mL) after 70 days of fermentation at 5°C. A similar observation was found in a previous study (25), whereas, in the kakdugi prepared with gamma-irradiated red pepper powder, the fermentation time for maximum counts of lactic acid bacteria was around 28 days with 8.5~8.7 (log CFU/mL). This result is consistent with the acidity and the amount of reducing sugar (Fig. 1 and 2). Although gamma-irradiated red pepper powder was used for kakdugi, the other ingredients used for making kakdugi were not sanitized and were a potential source of microbial contamination. At the start of fermentation, total or lactic acid bacteria number of kakdugi made with gamma irradiated red pepper powder were similar to the control. In addition, the changes in patterns of total yeast counts in kakdugi were similar to total lactic acid bacteria counts. The different growth rates for lactic acid bacteria and yeasts in kakdugi might be caused by the irradiated red pepper powder, which contained different initial levels of bacteria and yeasts count due to gamma-irradiation. At the initial fermentation period, higher amount of reducing sugar in control kakdugi may have been a product of lactic acid bacteria metabolism (26), which resulted higher concentrations than in the kakdugi prepared with irradiated red pepper powder.

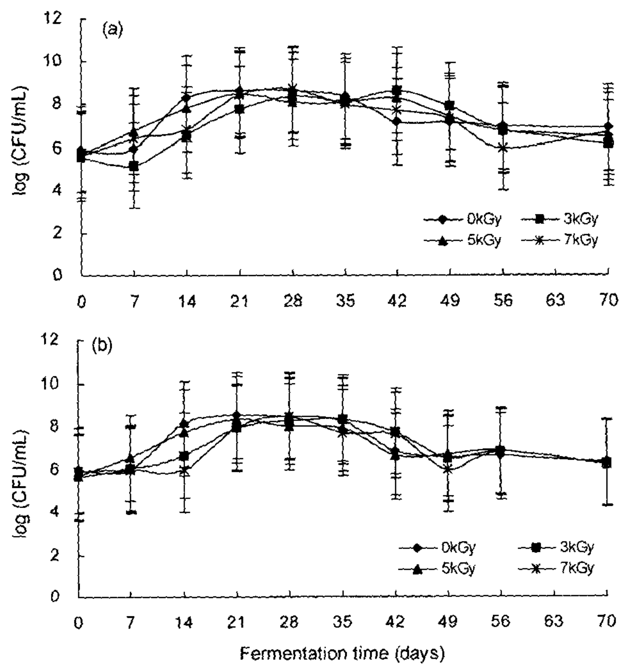

Fig. 3. Changes in total counts of lactic acid bacteria (a) and yeasts (b) of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

Color and ASTA unit

Color is an important quality attribute of kakdugi. Its red color is derived from red pepper powder. Kakdugi prepared with irradiated red pepper powder showed a higher Hunter color L*, a*, and b* values than those of control kakdugies shown in Fig. 4. Although the extent of increase was not consistent with the irradiation doses of up to 7 kGy, the changing pattern of Hunter color values during fermentation was similar to those of previous reports (25,27). Extractable color expressed as ASTA units has been reported to correspond well with total pigment concentration of red pepper powder containing red and yellow carotenoids (28). In the present study, ASTA units tended to increase as the irradiation dose increased and the ASTA unit showed a good correspondence with Hunter a* value up to 21 days (Fig. 5).

Texture

Textural properties of radish cubes in kakdugi measured by a texture analyzer are depicted in Fig. 6. Hardness, fracturability, and chewiness decreased slightly in both types of kakdugi during fermentation. These results are similar to those of previous reports (29). However, no significant differences were observed in hardness, chewiness or fracturability of radish cubes in kakdugi

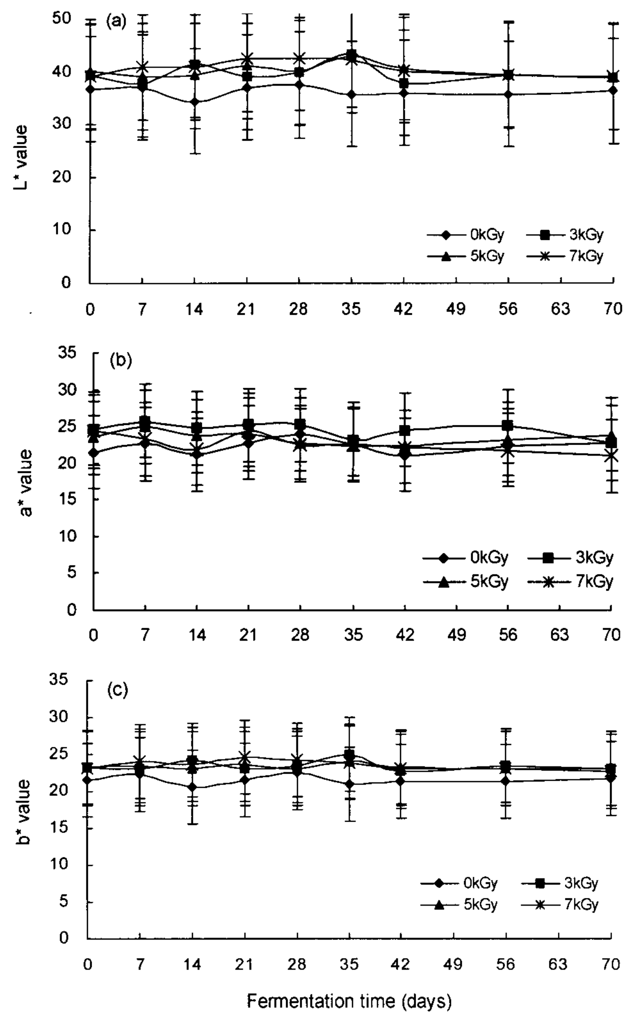

Fig. 4. Changes in Hunter color L* (lightness) (a), a* (±, redness/greenness) (b), and b* value (±, yellowness/blueness) (c) of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

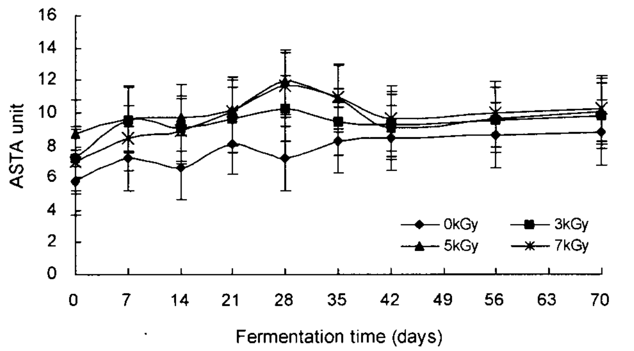

Fig. 5. Changes in ASTA unit of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

containing gamma-irradiated red pepper powder and non-irradiated control throughout the fermentation period ($p < 0.05$).

Sensory characteristics

Sensory evaluation results of kakdugi prepared with

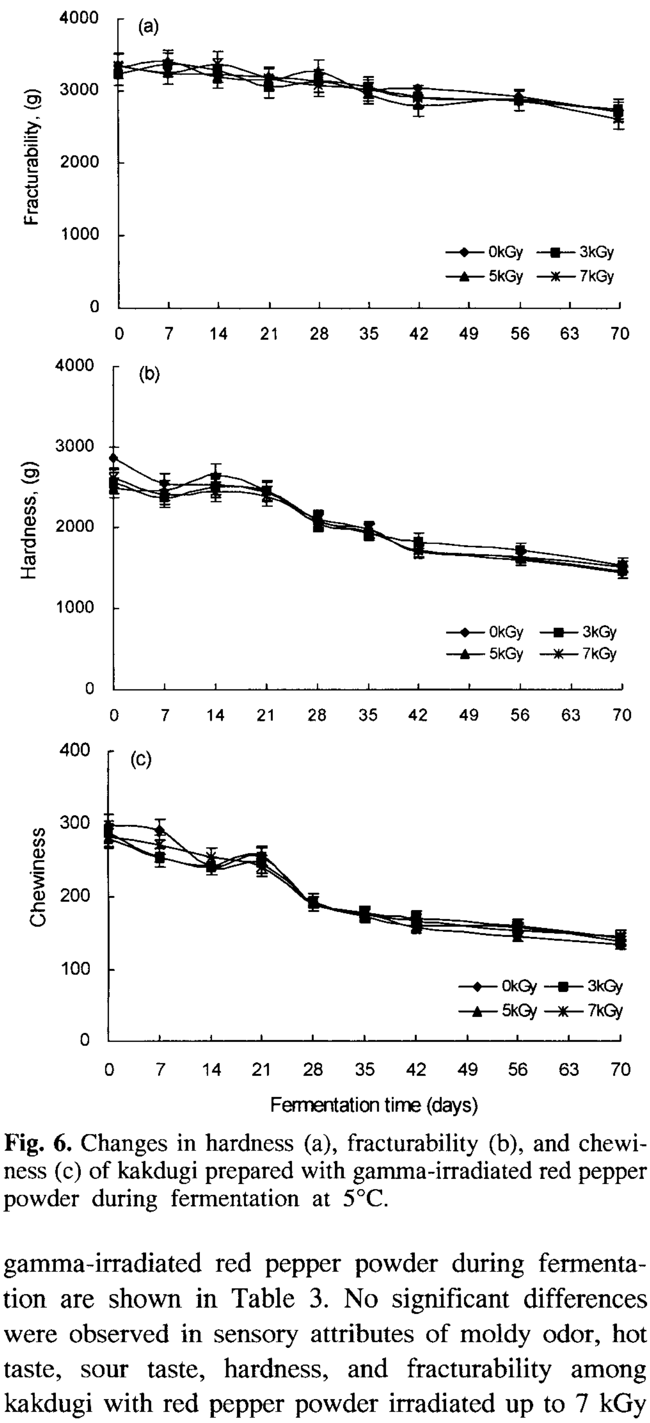

Fig. 6. Changes in hardness (a), fracturability (b), and chewiness (c) of kakdugi prepared with gamma-irradiated red pepper powder during fermentation at 5°C.

gamma-irradiated red pepper powder during fermentation are shown in Table 3. No significant differences were observed in sensory attributes of moldy odor, hot taste, sour taste, hardness, and fracturability among kakdugi with red pepper powder irradiated up to 7 kGy ($p < 0.05$). The sensory scores for color of kakdugi prepared with irradiated red pepper powder was significantly higher than those of kakdugi with non-irradiated red pepper powder at 21 and 35 days of fermentation ($p < 0.05$). These sensory results are related to the physicochemical evaluation of color expressed as ASTA units (Fig. 4). However, there was no significant difference in overall acceptability between kakdugi prepared with irradiated red pepper powder and non-irradiated control throughout the fermentation period, and the result showed that gamma irradiation of red pepper powder did not

Table 3. Mean scores of sensory evaluation of kakdugi prepared with gamma-irradiated red pepper powder and non-irradiated control during fermentation at 5°C[1,2)]

Fermentation (day)	Treatment (kGy)	Color	Moldy odor	Hot taste	Sour taste	Hardness	Fracturability	Overall acceptability
0	0	5.0[ns3)]	1.0	2.9[ns]	1.0	8.3[ns]	8.6[ns]	7.4[ns]
	3	5.5	1.0	2.8	1.0	8.2	8.6	7.2
	5	6.2	1.0	2.7	1.0	8.3	8.7	7.0
	7	5.8	1.0	3.0	1.0	8.6	8.8	7.2
21	0	4.9[b]	1.0	4.7[ns]	5.7[ns]	6.3[ns]	6.3[ns]	7.3[ns]
	3	4.3[b]	1.0	4.9	4.3	6.7	6.8	7.5
	5	5.6[a]	1.0	4.9	4.5	6.5	6.8	7.0
	7	5.1[a]	1.0	4.5	4.7	5.6	6.0	7.4
35	0	3.0[b]	3.0[ns]	2.0[ns]	7.0[ns]	6.0[ns]	6.0[ns]	6.0[ns]
	3	4.2[a]	1.9	3.0	6.2	5.6	5.7	6.1
	5	4.4[a]	1.9	3.3	6.3	5.6	5.8	6.2
	7	4.3[a]	2.0	3.1	6.8	5.5	5.7	6.2
42	0	4.6[ns]	2.5[ns]	3.9[ns]	7.3[ns]	4.2[ns]	4.8[ns]	4.8[ns]
	3	4.5	2.4	4.1	7.3	4.8	5.2	5.5
	5	4.5	2.3	4.0	7.3	4.7	5.2	5.2
	7	4.1	2.4	4.1	7.4	4.8	5.4	5.1
70	0	5.8[ns]	5.2[ns]	3.6[ns]	8.4[ns]	3.7[ns]	3.6[ns]	2.6[ns]
	3	5.3	3.4	3.8	8.6	4.3	4.1	4.5
	5	4.2	3.4	3.7	8.5	4.2	4.0	4.2
	7	4.6	3.4	3.8	8.5	4.2	4.0	4.5

[1)]Results are based on a hedonic scale. Highest rating is 10 for "strongest" and lowest is 1 for "weakest".
[2)]Mean values in the same column followed by different letters are significantly different ($p<0.05$) between irradiation treatments at the doses of 0, 3, 5, and 7 kGy by Duncan's multiple range test.
[3)]Not significant at $p<0.05$.

affect the sensory qualities of kakdugi except for color.

In conclusion, gamma-irradiation of red pepper powder up to 7 kGy did not affect either the physiochemical or sensory properties of kakdugi during the entire period of kakdugi fermentation. However, use of gamma-irradiated red pepper powder was favorable to maintaining red color and delaying optimum ripening time.

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