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Quality of Irradiated Plain Yogurt during Storage at Different Temperatures

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ABSTRACT : To develop a safer yogurt for immuno-compromised or allergy patients and to extend shelf-life, a plain yogurt was irradiated with doses of 0, 1, 3, 5, and 10 kGy using a gamma ray and the chemical and microbiological quality and allergenicity change were investigated. There was no difference in the content of protein, total solid, and amino acids of the plain yogurt by irradiation treatment and different storage temperatures (4, 20, and 35°C). The lactic acid bacterial counts of irradiated plain yogurt had approximately 3-decimal reduction at 3 kGy, and no viable cell at 10 kGy regardless of storage time and temperature. The binding ability of rabbit antiserum to milk proteins in irradiated plain yogurt showed that 10 kGy of irradiation produced significantly higher binding ability than other treatments. Sensory evaluation indicated that only appearance of the plain yogurt irradiated at 3 kGy or higher had a lower value than the non-irradiated control when stored at 20°C. Results suggest that irradiation of plain yogurt does not significantly affect the chemical and sensory quality of plain yogurt, but can extend the shelf-life, possibly reduce allergenicity, and provide a safer product. (**Key Words :** Plain Yogurt, Irradiation, Lactic Acid Bacteria, Allergenicity, Sensory)

INTRODUCTION

Yogurt, a sour milk product, is a fermented dairy food originated from the Balkans and the Middle East. Goats', ewes', and cows' milk are used for its manufacture (Teuber, 2000). Yogurt is usually manufactured with or without the addition of some natural derivatives of milk, and with the gel structure being the results of the milk proteins by lactic acid produced from different microorganisms such as *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* (Robinson, 2003). It possesses a fresh lactic acid smell and its taste is characteristic, pleasant, full, and slightly to intensely sour (Teuber, 2000). Because yogurt contains an abundant and viable microflora of starter origin at the time of consumption and low pH, it is considered generally safe if possible post-pasteurization recontamination is prevented (Varga, 2006). Antioxidant activity of some yogurt starter cultures also reported (Kim et al., 2005). However, the shelf life of yogurt products is usually 3 weeks or less at refrigerated storage in Korea. In addition, immuno-compromised patients can be suffered from these health-promoting microorganisms present in yogurt.

Irradiation technology has positive effects in preventing decay by sterilizing the microorganisms and by improving the safety and shelf-stability of food products without compromising the nutritional or sensory quality (World Health Organization, 1999; Gharaghani et al., 2008). Thus, the use of ionizing radiation has been gradually increasing worldwide. Song et al. (2004) suggested that the continuous microbiological activities in well-ripened *Kimchi* deteriorate the quality as results of acidification, softening and gas production. The authors used gamma irradiation to achieve uniformed and sustained quality of *Kimchi* (Song et al., 2004). However, it is very hard to find the literature for the quality of yogurt after irradiation and following storage. The reason must be that, in general, yogurt products thought to be safe on microbial contamination because of its low pH and dominant lactic acid bacteria. In addition, a bacteriostatic effect of yogurt as probiotics is widely accepted (Berrocal et al., 2002). In a legal aspect, only dried milk products for disinfestations (max. 3 kGy) and

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microbial control (max. 30 kGy) and casein or caseinates for microbial control (max. 6 kGy) are approved for irradiation in Croatia and Belgium, respectively (IAEA, 2008).

On the other hand, cow's milk allergy is known to the most common food allergy during infancy and early childhood (David, 1993; Docena et al., 1996). The primary allergens in cow's milk are casein proteins, β-lactoglobulin, α-lacalbumin, bovine serum albumin, and bovine serum IgG (Taylor, 1986). Among them, β-lactoglobulin is the most important allergen because it is not present in human milk (Savilahti and Kuitunen, 1992). For reducing the allergenicity in milk, an enzymatic hydrolysis with various proteolytic enzymes has been applied (Taylor, 1980; Asselin et al., 1989; Schmidl et al., 1994). However, these hypoallergenic formulas have an unsatisfactory taste caused by the presence of bitter peptides and amino acids (Lee et al., 2001a). In addition, the cases of an allergy to milk hydrolysate were reported (van Beresteijn et al., 1995; van Hoeyveld et al., 1998; Nillsson et al., 1999). Therefore, the new method to reduce or eliminate the allergenicity of milk or dairy products is needed.

Studies have demonstrated that food irradiation can reduce food allergy. Irradiation of proteins produces a structural denaturation (Hates et al., 1995), and creates changes in the binding ability. IgE-binding capacities of irradiated ovoalbumin and ovomucoid were reduced to 1/80 and 1/20, respectively (Lee et al., 2002b). The enhancement of immunomodulatory activity of fermented milk products can be maintained even though these lactic acid bacteria were biologically inactivated. It may be one of the promising ways of using food irradiation technology by adding value over microbiologically safer foods.

Therefore, the objective of present study was to evaluate the quality characteristics and sensory stability of irradiated plain yogurt when stored at refrigerated (4°C), room temperature (20°C), and abused storage temperature (35°C). In addition, the binding ability of rabbit antiserum to milk proteins in irradiated plain yoghurt was studied to see the possible means of irradiation for the reduction of allergenicity in plain yogurt.

MATERIALS AND METHODS

Sample preparation

A commercial starter (0.01%, CHR HANSEN ABT-5, Copenhagen, Denmark) was inoculated into defatted pasteurized milk at 92°C for 10 min and incubated at 37°C for 5.5 h. The composition of starter was *Lactobacillus acidophilus*, *L. bulgaricus*, and *Streptococcus thermophilus*. The stirred yogurt was cooled, put into plastic sample cup (120 g), covered with lid individually, and transferred to irradiation facility in a cooler with ice bag.

Gamma irradiation

The plain yogurt in plastic cup was irradiated in a cobalt-60 gamma irradiator (point source, ACEL, IR-79, MDS Nordion, Ontario, Canada) located at the Korea Atomic Energy Research Institute, Jeongeup, Korea. The source strength was approximately 410 kCi with a dose rate of 20 kGy/h at 18±0.5°C. Dosimetry was performed using 5 mm diameter alanine dosimeters (Bruker Instruments, Rheinstetten, Germany), and the free radical signal was measured using a Brucker EMS 104 EPR Analyser. The dosimeters were calibrated against an international standard set by the International Atomic Energy Agency (Vienna, Austria). The applied doses in this study were 0, 1, 3, 5 and 10 kGy with a carton box outside of the inner box (sample cups were placed longitudinally) with ice bag in between to avoid temperature increase during process. After irradiation, the samples were transferred to a laboratory using a cooler and stored at different temperatures set at 4, 20, and 35°C for further analysis.

Lactic acid bacterial count

The yogurt sample (10 g) was aseptically homogenized for 2 min in a sterile stomacher bag containing 90 ml of sterile 0.1% peptone water using a stomacher (bag mixer® 400, Interscience Co, France). Medium for the enumeration of the lactic acid bacteria was prepared by a BCP plate count agar (Eiken Co., Tokyo, Japan). The plates were incubated at 37°C for 48 h and the colony forming units (CFU) per gram were counted at a dilution of 30 to 300 CFU per plate. Experiments with each bacteria culture were independently conducted twice.

pH

Samples (5 g) and distilled water (20 ml) were homogenized by a homogenizer (DIAX 900, Heidolph, Schwaabach, Germany). The pH of the homogenate was measured using a pH meter (Mettler-Toledo, GmbH, Schwerzenbach, Switzerland).

Chemical analysis

Protein, lactic acid, lactose, and total solid contents of the yogurt samples were measured by MilkoScan FT120 (Foss Electric, Hillerod, Denmark). For amino acid composition, approximately 1 g of a yogurt sample was weighed into a sample bottle, and 40 ml of 6 N HCl was added to the bottle while purging it with nitrogen gas. After a hydrolysis at 110°C for 24 h, HCl was removed at 50°C by using a rotary evaporator (Eyela, Tokyo, Japan). The residues were washed with distilled water 3 times and evaporated, and then filtered through a filter paper (Toyo, No. 5B, Tokyo, Japan). The filtrate was messed up to 50 ml with distilled water, and analyzed by an amino acid analyzer (Hitachi L-8500A, Tokyo Japan). Cysteine and

Table 1. General composition of irradiated plain yoghurt

Irradiation dose (kGy)	Protein (%)	Lactic acid (%)	Lactose (%)	Total solid (%)
0	3.39±0.02[1]	0.74±0.01^{b}	4.02±0.03	8.71±0.03
1	3.39±0.04	0.85±0.01^{a}	4.19±0.01	8.72±0.05
3	3.31±0.06	0.82±0.01^{a}	4.21±0.02	8.67±0.05
5	3.39±0.02	0.83±0.01^{a}	4.20±0.02	8.72±0.04
10	3.37±0.01	0.81±0.02^{a}	4.17±0.01	8.69±0.01

[1] Mean±standard deviation. $^{a, b}$ Different letters within the same row differ significantly ($p<0.05$).

methionine were changed to cysteic acid and methionine sulfone by adding 20 ml of a stabilizing solution (45 ml of 85% formic acid+5 ml of 30% H_2O_2) before the addition of HCl.

Binding ability of yogurt protein to rabbit antiserum

IgG ELISA was performed as described by Elsayed et al. (2004) with some modifications. Six rabbits were immunized with skim milk. Immunization was generally done using as follows; 0.5 ml of antigen (1 mg/ml sterile NaCl, 0.9%) in suspension with 0.5 ml Freund's Complete Adjuvant was injected in each animal at week 1. In weeks 3 and 5, each animal was injected with booster dose 0.5 ml (1 µg/µl) in suspension with 0.5 ml Freund's Incomplete Adjuvant. The rabbit sera were tested for antibody production before each and after the third immunization. The animals were bled about 14 days after the last immunization. Sera were collected and stored at -80°C. Ninety-six wells, flexible round-bottom, microtitre plates (NUNC, Maxisorp, Denmark) were coated with 200 µl of 0.01% skim milk in a 0.1 M sodium bicarbonate buffer (pH 9.5) for 24 h at 4°C. After washing then three times with a PBS containing 0.05% Tween-20 (PBS-Tween), 100 µl of rabbit IgG sera diluted to 1/70,000 with PBS-Tween, and 100 µl of each yogurt sample was added, and washed with Tween-20 after a 1 h incubation at 37°C. An anti-rabbit IgG-alkaline phosphatase conjugate (100 µl, Sigma A8025) diluted to 1/1,000 with Tween 20 was added to each well. After one hour, 100 µl of 1 mg/p-nitrophenylphosphate (Sigma N-9389) in a 1 M diethanolamine buffer (pH 9.8) was added and incubated for 30 min. Then, 20 µl of 5 N NaOH was added to each well and the absorbance was measured at 405 nm using Spectramax PLUS 384 (Molecular Devices, CA, USA).

Sensory evaluation

Semi-trained panelists (n = 15), who are graduate students and staff member with different experiences for sensory evaluation of irradiated foods, were used to evaluate sensory properties of plain yogurt. All the panelists were aware of characteristic irradiation off-odor. The sensory parameters were appearance color, odor, taste, off-flavor intensity and overall acceptability. A 9-point hedonic scale was provided to the panelists as follows: like very much (9), neither like nor dislike (5), and dislike very much (1). For off-flavor, the scale was: no off-flavor (1) to very strong off-flavor (9). Sensory analysis was performed immediately after irradiation and after 7 days of storage at 4, 20, and 35°C.

Statistical analysis

All measurements were performed in triplicate, and analysis of variance was conducted by the General Linear Model procedure using SAS software (1995). When significance ($p<0.05$) was found, the differences among the mean values were identified by Duncan's multiple range test.

RESUTLS AND DISCUSSION

The content of protein, lactic acid, lactose, and total solid were 3.39, 0.74, 4.02, and 8.71% in non-irradiated control, respectively and there was no difference found in the content of protein and total solid by irradiation treatment (Table 1). However, the content of lactic acid increased ($p<0.05$) when the sample was irradiated at 1 kGy or higher. Previous study showed that decrease of pH value in milk by irradiation (Ham et al., 2005). It has been reported that generally, the titratable acidity of the milk increases while the pH decreases by heat treatment. However, there are large differences among milk and the changes may be influenced by other factors as well (Walstra and Jenness, 1984). Adeil Phietranera et al. (2003) used irradiation for providing a safer ice creams to immuno-compromised patients and concluded that no major alteration on the macronutrients fractions is expected in irradiated ice creams when low irradiation doses (less than 3 kGy) is employed and the product is frozen state. The pH of plain yogurt was ranged 4.35-4.45 and not differ by irradiation up to 10 kGy dose immediately after irradiation. However, when it was stored at 35°C the pH values of 0 and 1 kGy irradiated yogurt were lower than those of 3, 5, and 10 kGy irradiated samples after 1 week storage (data not shown). It may be due to the reduction of the lactic acid bacterial number by irradiation treatment.

Protein content of irradiated plain yogurt did not show any difference either the initial storage time after irradiation or the final storage after 3 weeks from irradiation regardless of storage temperatures (Data not shown). This implies that

Table 2. Amino acid content of irradiated plain yoghurt

Irradiation dose (kGy)	ALA	ARG	ASP	CYS	GLU	GLY	HIS	ILE	LEU	LYS	MET	PHE	PRO	SER	THR	TYR	VAL
0	115.5[1] ±1.9	109.5 ±1.9	254.8 ±3.6	35.0 ±0.0	692.0 ±4.1	65.8 ±2.1	82.8 ±0.5	147.0 ±1.4	320.5 ±3.1	253.3 ±3.3	70.0 ±0.0	156.0 ±1.4	323.5 ±7.7	186.5 ±1.7	146.0 ±1.6	158.5 ±1.7	183.8 ±2.9
1	112.3 ±1.7	103.3 ±2.5	248.8 ±4.6	35.5 ±0.6	681.5 ±9.0	62.5 ±1.7	81.3 ±1.0	145.5 ±0.6	316.0 ±4.7	251.3 ±3.5	70.5 ±1.7	151.5 ±1.9	322.0 ±9.4	181.8 ±3.3	142.8 ±2.6	154.3 ±1.7	181.0 ±3.4
3	112.5 ±2.1	101.3 ±5.0	240.0 ±5.5	36.0 ±2.3	673.0 ±14.8	62.0 ±1.4	79.8 ±2.1	142.0 ±1.8	313.3 ±7.8	248.8 ±6.1	69.5 ±2.9	151.0 ±3.5	313.3 ±16.5	181.3 ±3.8	142.5 ±3.4	153.3 ±3.0	181.8 ±2.1
5	115.5 ±1.0	104.5 ±3.1	253.8 ±1.0	36.5 ±0.6	683.5 ±6.6	65.0 ±1.6	90.0 ±1.3	146.8 ±2.2	321.3 ±4.3	253.0 ±3.2	68.0 ±0.0	153.3 ±1.0	313.5 ±32.2	188.0 ±2.9	146.5 ±1.0	152.8 ±3.3	187.5 ±3.8
10	112.5 ±0.6	108.0 ±1.2	252.3 ±1.5	37.0 ±0.0	690.0 ±2.2	62.5 ±0.6	82.3 ±1.5	143.0 ±2.4	322.3 ±4.4	254.8 ±3.3	69.0 ±2.3	152.8 ±2.2	317.3 ±4.8	185.0 ±0.0	145.0 ±1.2	155.8 ±1.0	179.0 ±1.4

[1] Mean±standard deviation.

neither irradiation nor storage temperature and time affect on protein content of plain yogurt. Amino acid contents of the plain yogurt also did not show any difference by irradiation dose after irradiation (Table 2). Ham et al. (2008) reported that the contents of certain amino acids of milk including Arg, Asp, Glu, Ile, Leu, Lys, Pro, Ser, Thr, and Try were lower in 10 kGy-irradiated samples than those treated by ultra high temperature (UHT, 135°C for 4 s). The authors also indicated that, however, no difference was observed between irradiated milks at less than 5 kGy and ultra high temperature (UHT) treated ones.

Table 3 shows the lactic acid bacterial counts of irradiated plain yogurt when stored at different temperature for 3 weeks. When irradiation was applied, the number of lactic acid bacteria showed approximately 3-decimal reduction at 3 kGy and no viable cell was detected at 10 kGy. After storage at 4°C for 2 and 3 weeks, the number of lactic acid bacteria decreased slightly in the sample irradiated at 3 and 5 kGy. However, no viable cell was detected in the sample irradiated at 10 kGy regardless of storage time and different temperatures. Results indicated that storage temperature affected on the growth of lactic acid bacteria in plain yogurt, especially in irradiated samples. When the sample stored at room temperature (20°C) for 2 and 3 weeks, the number of bacteria survived reduced significantly compared with those stored for 1

Table 3. Lactic acid bacterial counts of irradiated plain yoghurt during storage for 3 weeks with different storage temperatures

Storage (week)	Irradiation dose (kGy)	Storage temperature (°C)		
		4	20	35
0	0		8.95±0.02^{1,a}	
	1		8.23±0.04^{b}	
	3		5.80±0.30^{c}	
	5		4.00±0.21^{d}	
	10		ND^{e}	
1	0	9.03±0.11^{ax}	8.00±0.08^{by}	6.21±0.15^{az}
	1	8.59±0.13^{bx}	8.47±0.05^{ax}	4.82±0.18^{by}
	3	6.42±0.03^{cy}	7.16±0.03^{cx}	ND^{cz}
	5	5.86±0.05^{dx}	4.78±0.06^{dy}	ND^{cz}
	10	ND^{e}	ND^{e}	ND^{cz}
2	0	9.13±0.01^{ax}	8.72±0.01^{ay}	4.92±0.11^{az}
	1	8.47±0.02^{bx}	7.99±0.05^{by}	1.15±0.21^{bz}
	3	5.93±0.04^{cx}	3.01±0.28^{cy}	ND^{cz}
	5	4.23±0.04^{dx}	0.15±0.21^{dy}	ND^{cy}
	10	ND^{e}	ND^{d}	ND^{c}
3	0	9.28±0.01^{ax}	8.15±0.08^{ay}	1.75±0.21^{az}
	1	8.43±0.02^{bx}	6.53±0.12^{by}	1.30±0.01^{az}
	3	2.85±0.02^{cx}	1.54±0.09^{cy}	ND^{bz}
	5	4.24±0.12^{dx}	0.15±0.11^{dy}	ND^{by}
	10	ND^{e}	ND^{d}	ND^{b}

[1] Mean±standard deviation.

$^{a-e}$ Means with different letters in the same column with the same storage day significantly different ($p<0.05$).

$^{x-z}$ Means with different letters in the same row differ significantly ($p<0.05$).

Table 4. Binding of rabbit antiserum to milk proteins in plain yoghurt after irradiation

Irradiation dose (kGy)	Protein concentration (μg/)						
	1,000	100	10	1	0.1	0.01	0.001
0	0.16±0.00^{b}	0.17±0.01^{ab}	0.31±0.01^{ab}	0.50±0.00^{a}	0.62±0.00^{b}	0.66±0.02^{b}	0.65±0.02^{b}
1	0.16±0.00^{b}	0.16±0.01^{b}	0.28±0.00^{b}	0.48±0.02^{a}	0.61±0.02^{b}	0.66±0.02^{b}	0.64±0.02^{b}
3	0.15±0.00^{b}	0.16±0.01^{b}	0.28±0.00^{b}	0.50±0.02^{a}	0.61±0.02^{b}	0.66±0.01^{b}	0.66±0.04^{ab}
5	0.15±0.01^{b}	0.16±0.01^{b}	0.29±0.01^{b}	0.49±0.02^{a}	0.64±0.00^{b}	0.67±0.02^{b}	0.67±0.02^{ab}
10	0.18±0.01^{a}	0.19±0.01^{a}	0.32±0.01^{a}	0.53±0.02^{a}	0.70±0.01^{a}	0.73±0.01^{a}	0.71±0.02^{a}

[1] Mean±standard deviation. [a, b] Different letters within the same column differ significantly ($p<0.05$).

week. This tendency was more apparent when the storage temperature was increased to 35°C. At this storage temperature the lactic acid bacteria in plain yogurt irradiated at 3 kGy or higher doses were not detected (Table 3). In addition, the microbial population in the sample with the same storage temperature showed a tendency to decrease during storage after irradiation. It may be due to the post-irradiation effect where the surviving cells that had been damaged by an irradiation were gradually inactivated, thus not adapting to the surrounding environment during storage (Song et al., 2007).

In general, yogurt products thought to be safe on microbial contamination because of its low pH, dominant lactic acid bacteria, and prebiotics feature. Kim and Yoon (1998) did not detect *Listeria monocytogenes, Escherichia coli* O157:H7, and coliforms in commercial frozen yogurt products but the viable lactic acid bacteria in the products were 8-6 log CFU/g levels. Jo et al. (2007) reported that the D_{10} values of *Listeria ivanovii* and *E. coli* were 0.75 and 0.31 kGy, respectively when inoculated into vanilla ice cream. In the same study, *Salmonella* Typhimurium was too sensitive to detect even at 0.1 kGy of irradiation dose. In the present study, the combination of bacteriostatic effect of yogurt, low pH, and irradiation may provide difficult hurdles for pathogens to survive, if contaminated.

Using a rabbit serum antibody, the binding ability of rabbit antiserum to milk proteins in irradiated plain yogurt was tested (Table 4). With different concentrations it was clearly shown that the plain yogurt irradiated at 10 kGy was significantly higher binding ability than non-irradiated control or up to 5 kGy of irradiated samples. Irradiation of proteins produces a structural denaturation and creates changes in the binding ability of IgE against allergens (Hates et al., 1995). The IgE ELISA inhibition test indicated the IgE-binding capacities of irradiated ovalbumin and ovomucoid were reduced significantly (Lee et al., 2002). When bovine α-casen and β-lactoglobulin in milk were used, the allergenicity and antigenicity of irradiated proteins were changed by different slopes of the inhibition curves. The authors explained that the disappearance of band on SDS PAGE and increase of turbidity demonstrated the decrease of solubility of the milk proteins by irradiation, and concluded that this decrease might be caused by agglomeration of the proteins (Lee et al., 2001b). The results can be summarized that epitopes on milk allergens can be structurally altered by irradiation and agreed well with the present study. Recently, different model food allergens have been monitored to examine the reduction of their allergenicity by irradiation with success (Byun et al., 2000; Lee et al., 2001a). Also clinically significant result on the reduction of allergy from irradiated allergen was reported (Jeon et al., 2002).

Table 5 represents sensory evaluation of irradiated plain yogurt at 2 h after irradiation. There was no significant difference found by irradiation up to 10 kGy. After 1 week, the sensory evaluation was performed again with different storage temperatures (Table 6). Only appearance of the plain yogurt irradiated at 3 kGy or higher scored lower than those of non-irradiated control when stored at 20°C. Without statistical significance, the higher storage temperature had a tendency to lower score in appearance. The irradiation characteristic off-odor was not detected by increase of irradiation doses. It is very limited information available for the effect of irradiation on the sensory change

Table 5. Sensory evaluation of irradiated plain yogurt at day 0[1]

Sensory parameter	Irradiation dose (kGy)					
	0	1	2	3	5	10
Appearance	5.8±2.39[2]	6.0±2.40	5.9±2.42	5.9±2.42	5.9±2.42	5.9±2.42
Color	5.7±1.66	6.3±1.41	6.3±1.66	6.4±1.59	6.3±1.66	6.3±1.66
Odor	5.3±2.18	5.6±2.13	5.6±2.19	5.6±2.19	5.7±2.29	5.7±2.29
Taste	3.4±2.07	3.9±2.03	4.1±1.54	4.3±1.80	4.0±1.87	4.0±1.80
Off-flavor	5.0±2.40	5.3±2.65	5.0±2.18	4.9±2.20	4.2±2.05	4.8±2.39
Overall acceptance	4.6±1.67	4.6±1.74	4.8±1.48	4.7±1.22	4.8±1.30	4.4±1.51

[1] A 9-point hedonic scale was used: like very much (9), neither like nor dislike (5), and dislike very much (1). For off-flavor, the scale was: no off-flavor (1) to very strong off-flavor (9).

[2] Mean±standard deviation.

Table 6. Sensory evaluation of irradiated plain yogurt stored for 1 week at different storage temperatures

	Irradiation dose (kGy)					
	0	1	2	3	5	10
4°C						
Appearance	6.1±0.99	6.0±0.94	5.9±1.10	5.9±1.10	5.9±1.10	5.9±1.190
Color	5.1±1.52	5.6±1.26	5.7±1.16	5.7±0.95	6.0±0.94	6.1±1.10
Odor	5.8±0.92	6.1±0.87	5.9±0.88	5.6±1.01	5.6±1.12	5.5±0.86
Taste	5.0±1.33	5.2±0.92	5.2±0.63	5.2±0.63	5.4±0.70	4.6±0.97
Off-flavor	2.6±2.12	2.8±1.62	4.4±2.37	3.9±2.18	3.8±2.35	4.5±2.84
Overall acceptance	4.7±1.34	5.1±1.29	5.1±1.20	4.9±1.52	4.9±1.29	4.6±1.07
20°C						
Appearance	6.1^{a}±0.88	5.6^{ab}±0.84	5.3^{ab}±0.82	5.0^{b}±1.05	5.1^{b}±0.88	5.1^{b}±0.88
Color	5.8±0.92	5.7±0.82	5.6±0.70	5.4±0.84	5.2±1.14	5.2±1.14
Odor	5.7±1.06	5.9±0.99	5.9±1.20	5.5±1.08	5.9±1.29	5.7±1.16
Taste	4.6±1.58	4.9±0.99	4.7±1.06	5.3±1.16	4.8±1.14	5.4±1.35
Off-flavor	4.3±1.57	4.7±0.95	4.9±1.10	4.5±0.85	4.8±1.32	4.3±1.34
Overall acceptance	4.4±1.65	4.8±1.55	4.7±1.34	5.2±1.23	4.6±1.65	5.3±1.77
35°C						
Appearance	5.2±1.32	5.1±1.10	5.0±0.94	4.7±1.25	4.7±1.06	4.5±1.27
Color	5.6±1.26	5.6±0.97	5.3±1.16	5.1±1.10	4.9±0.99	4.6±1.51
Odor	5.5±0.85	5.4±0.84	5.4±0.97	5.2±1.03	5.3±0.95	5.1±0.88
Taste	3.5±1.96	3.6±1.96	4.0±1.70	4.2±1.93	4.9±1.85	4.6±1.65
Off-flavor	4.3±1.95	4.3±1.70	4.6±1.58	4.4±2.01	4.5±2.07	4.1±2.02
Overall acceptance	3.8±1.48	4.0±1.33	4.2±1.32	4.4±1.43	4.8±1.55	4.6±1.35

[a,b] Different letters within the same row differ significantly ($p<0.05$). [1] Mean±standard deviation.

of yogurt. It is assumed that relatively strong sour taste of the plain yogurt may mask the possible flavor change. When sensory triangle test was performed to differentiate among the treatments of LTLT (low temperature long time, 63°C, 30 min), UHT-, and 3 kGy-irradiated milk, all panelists were able to differentiate between LTLT- or UHT- and irradiation-treated milk at 3 kGy (Ham et al., 2008). In the same study, a slight cooked odor was commented from sensory panelists in UHT-treated milk when compared with LTLT-treated one and irradiation of 3 kGy resulted into characteristic metallic odor which can be detectable. Jo and Ahn (2000) suggested that radiolysis of protein or amino acid may play an important role in characteristic irradiation off-odor because the irradiation off-odor was different from oxidized one. Abdel Baky et al. (1986) reported that an oxidized flavor in the fresh and 1-month-old irradiated milk cheese disappeared during ripening. At the end of ripening, an irradiated cheese had a better consistency and increased flavor compared with cheese made from heat pasteurization.

Results indicated that irradiation of plain yogurt can provide proper nutritional and sensorial quality for consumers with possible advantage of allergy reduction. Shelf-life extension of yogurt products is also expected by the results of different storage temperatures at 4, 20, and 35°C. On the basis of the present study irradiation of 10 kGy is recommended to provide the sterilized and safer plain yogurt for consuming even immuno-compromised patients with possible reduction of allergenicity. A further study of the irradiation effect on plain yogurt is needed for clarification and practical application.

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