Assessment of microbiological contamination in *saengshik* products from the Korean market and identification of the irradiation status

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Abstract This study investigated the prevalence of microbiological contamination in commercial *Saengshik* products (samples SP-1 to SP-12) from the Korean market, and identified their irradiation status. SP-2, SP-8, and SP-12 showed less than 3.66 and 1.10 log colony forming units (CFU)/g in total plate and coliforms counts, respectively, while the remaining samples showed more than 4.70 and 2.35 log CFU/g, respectively. Four samples were positive on some of foodborne pathogenic bacteria (*Clostridium perfringens*, *Escherichia coli* O157:H7, and *Bacillus cereus*). SP-2, SP-8, and SP-12 contained no pathogenic bacteria and were suspected to have been irradiated. They were confirmed as positive using photostimulated luminescence (PSL) analysis. PSL positive results on samples SP-2, SP-8 and SP-12 were finally confirmed by the authentic thermoluminescence (TL) analysis on the basis of TL glow curve shape, intensity, temperature range of TL peak maxima and TL ratio (TL₁/TL₂).

Keywords *Saengshik* · Microbial safety · Food irradiation · Photostimulated luminescence · Thermoluminescence

Introduction

Saengshik is a formulated uncooked food popular among health-conscious people in Korea [1, 2]. According to Ministry of Food and Drug Safety (MFDS) [3], *saengshik* consists of group of food components in uncooked form such as, liquid, paste, bar, gel, granules or other food types of animal or plant origin. *Sageshik* processing involves drying which is used as such or usually mixed with water or other materials. Raw materials for *saengshik*, such as whole grains, legumes, fruits, vegetables, seeds, beans, seaweeds, mushrooms, and other natural ingredients, are pulverized after drying and then blended. Thermally-labile minerals, vitamins and phytochemicals along with digestive enzymes present in *saengshik* powder products are preserved owing to non-thermal processing of *saengshik* [1–3]. Kim et al. [4] regarded *saengshik* as an effective antidiabetic supplement after studying inhibitory activity of 26 ingredients in *saengshik* against α -amylase and α -glucosidase. *Saengshik* improved the liver protective effect in CCl₄-induced hepatotoxicity in mice [2]. In another study, *saengshik* was shown to alleviate the side-effects of chemotherapeutic anti-cancer agents in mice, suggesting that *saengshik* might be helpful in cancer patients receiving chemotherapy [5].

Microbial contamination of *saengshik* products is possible because no heat treatment is used during the manufacturing process. Commercial *saengshik* products in Korea were previously found to be contaminated with foodborne pathogens, such as *Bacillus cereus*, *Clostridium perfringens*, and *Escherichia coli* [6–8]. However, some raw ingredients for *saengshik*, such as pulverized grains, legumes, and mushrooms, are allowed to be treated by ionizing radiation (gamma-rays and electron beam) at a dose of up to 5 kGy, according to the Korean Food

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Standards Codex [9]. Therefore, it is possible that *saengshik* manufacturing companies in Korea might use irradiation technology (non-heat processing) to reduce microbial contamination in *saengshik* products.

Mandatory labeling is being enforced by regulatory authorities in many countries, including Korea, to promote marketing of irradiated foods and to ensure consumer's choice about selection of irradiated foods and non-irradiated foods. Irradiation facilities are also required to follow related regulations for the processing of food materials [10, 11]. For example, according to European legislation, labeling of foods or food ingredients is mandatory and each Member State has to carry out necessary checks every year on irradiated foods at the marketing stage [12]. In this context, effective and reliable identification methods are of prime importance to check conformance with applied regulations [13]. Photostimulated luminescence (PSL) [14] and thermoluminescence (TL) [15] have been adopted as the standard methods (for screening and confirmatory analysis, respectively) by the European Union, and are also endorsed by the Korean Food Standards Codex, to detect various irradiated foodstuffs [16–20].

This study was aimed to analyze the levels of microbial contamination in *saengshik* products available in the Korean market. Commercial samples were evaluated for total plate counts, yeasts and molds, coliforms, and foodborne pathogenic bacteria such as *C. perfringens*, *E. coli* O157:H7, and *B. cereus*. Direct epifluorescent filter technique/aerobic plate count (DEFT/APC) microbiological screening analysis was performed to investigate the pre-decontamination treatment of unknown samples. The potential of PSL and TL luminescence-based techniques was evaluated to determine the irradiation status of commercial *saengshik* products.

Materials and methods

Sampling and microbiological analysis of *saengshik* products

Twelve *saengshik* products (named SP-1 to SP-12) from different manufacturing companies were bought from three local markets in Daegu or Seoul in Korea, in their original polyethylene packing containing of 30–40 g, in July 2013. All samples were analyzed for total plate counts, yeasts and molds, and coliforms. A 10 g powder aliquot was taken aseptically from each sample and mixed with 90 mL sterile peptone water for 90 s using a stomacher (BA 7021, Seward Medical Ltd., Worthing, UK). Subsequent dilutions were prepared and plated on plate count agar (BD DifcoTM, NJ, USA) for total plate counts, potato dextrose agar (BD DifcoTM) acidified with 10% tartaric acid) for yeasts and

molds, and desoxycholate agar (BD DifcoTM) for coliforms. Microbial counting was performed for 24–48 h after incubation at 35–37 °C for total plate counts and coliforms. Colony counting for both yeasts and molds was performed after three days after completion of incubation period at 25 °C.

All samples were analyzed for *C. perfringens*, *B. cereus*, and *E. coli* O157:H7. Pathogen *C. perfringens* was grown in anaerobic culture in a cooked meat broth for 18–24 h at 35–37 °C. The enrichment broth was inoculated on *C. perfringens* agar (BD DifcoTM) base containing egg yolk and kanamycin (200 µg/mL) or tryptose sulfite cycloserine agar (BD DifcoTM) containing egg yolk and incubated at 35–37 °C for 18–24 h under anaerobic conditions. Yellowish colonies with bumpy rings (diameter, 2 mm) on *C. perfringens* agar base, and colonies with grayish turbid rings on tryptose sulfite cycloserine agar (BD DifcoTM) were identified. Confirmatory tests were conducted according to a previously published method [21]. For *B. cereus* detection, 10 g of sample was homogenized with 90 mL phosphate buffered saline and one loopful was streaked onto mannitol egg yolk polymyxin agar (Oxoid, Basingstoke, UK) with 10% egg yolk emulsion and *B. cereus* selective supplements. After incubation at 30 °C for 24 h, presumptive colonies (rough and dry with a bright pink background, surrounded by an egg yolk precipitate) were streaked onto nutrient agar (BD DifcoTM). Colonies from nutrient agar were subjected to β-hemolysis and motility tests. The presence of *B. cereus* was confirmed using an analytical profile index (API) CHB/E kit (Bio-merieux, Boston, MA, USA). For *E. coli* detection, 10 g of each sample was cultured in modified mEC broth (Oxoid) containing novobiocin supplement for 24 h at 35 °C. Colonies were subjected to biochemical tests, which included Kligler iron agar, and indole and oxidase tests. The presence of *E. coli* was confirmed using an API 20E kit (Bio-merieux).

DEFT/APC analysis

The DEFT/APC microbiological screening analysis was performed according to the EN 13783 standard protocol [22]. The first step of this analysis includes membrane filtration to capture the microorganisms, followed by staining with the fluorochrome, acridine orange. The membrane is then rinsed after staining and fixed on a microscope slide for counting under an epifluorescent microscope [20, 23]. The method is quick and a full analysis can be completed in 25–30 min.

PSL analysis

PSL analysis was performed using a PPSL Irradiated Food Screening System (serial 0021, SURRC; Scottish Universities Research and Reactor Center, Glasgow, UK). The standard method EN 13751 [14] was followed for sample preparation, measurement of photon counts (PCs), and interpretation of the results. Each sample was placed in a 55 × 12 mm diameter disposable petri dish (Green Cross, Gyeonggi-do, Korea) in a uniform thick layer without any specific sample treatment and measurements were performed by employing sample chamber under passive light conditions. The radiation-induced PSL signals emitting per second from the irradiated samples were automatically accumulated by a personal computer for up to 60 s. After every 10 negative results, blank trials were carried out and same was repeated after a positive result. PSL photon counts less than 700 counts/60 s were referred to as negative (non-irradiated), and greater than 5000 counts/60 s were recorded to be positive (irradiated) [14]. The revised standard EN 13751 [14] recommends calibrated PSL measurements to estimate the PSL sensitivity of the sample in cases of doubtful results. After initial PSL measurements, all samples were subjected to a calibration radiation dose of 1 kGy and then processed for second PSL measurements of calibrated PSL. For the irradiation treatment, all samples were taken to the Korean Atomic Energy Research Institute (KAERI, Jeongseup, Korea) and treated with gamma rays using a Cobalt-60 gamma-ray source (AECL, IR-79, Nordion International Co. Ltd., Ottawa, ON, Canada) at 1 kGy at a dose rate of 2.1 kGy/h at room temperature. Dosimetry was performed using alanine dosimeters with a diameter of 5 mm (Bruker Instruments, Rheinstetten, Germany).

TL analysis

The standard method as described by the EN 1788 [15] was followed to perform the TL analysis. Density separation procedure was used to separate minerals from each sample (100 g). Clean stainless steel discs were used for deposition of isolated minerals and were kept overnight in dry oven at 50 °C of temperature. TL reader (Harshaw 4500, Thermo Fisher Scientific Inc. Waltham, MA, USA) was used to record TL measurements at temperature range of 50–400 °C with heating rate of 6 °C/s. First glow curve (TL₁) was obtained from first-read out measurement performed on extracted minerals. Normalization of TL response was carried out by re-irradiating the samples at 1 kGy of dose as described earlier. Once again the discs were subjected to overnight storage at 50 °C of temperature in a dry oven. The measurement was performed again in order to obtain the second glow curve (TL₂). Throughout

all the procedure, full-process blanks were made and sample discs were used to perform measurements. Samples were classified in terms of their status (non-irradiated or irradiated) on the basis of TL glow curve shape, intensity, temperature range of TL peak maxima, and the TL ratio (TL₁/TL₂).

Statistical analysis

All measurements were performed in triplicate ($n = 3$) and the results were shown as the mean value ± standard deviation. Excel version 2007 (Microsoft, Redmond, WA, USA) and Origin 8.0 (OriginLab, Northampton, MA, USA) were used for the data analysis.

Results and discussion

Microbial contamination of saengshik products

A high degree of variability was observed in the levels of microbial contamination among commercial *saengshik* products from different manufacturing companies (Fig. 1). Total plate counts ranged from 2.41 to 7.97 log CFU/g. Yeasts and molds were in the range of 3.20 to 6.00 log CFU/g. Coliforms varied from 1.10 to 4.29 log CFU/g. Three samples, SP-2, SP-8 and SP-12, showed less than 3.66 log CFU/g in total plate counts and 1.10 log CFU/g in coliforms, while the other nine samples showed more than 4.70 and 2.35 log CFU/g in the corresponding microbial counts, respectively (Fig. 1). *E. coli* O157:H7 was found in three samples SP-4, SP-5, and SP-9. Two samples, SP-7 and SP-9, were positive for *C. perfringens*. Pathogen *B.*

Fig. 1 Microbiological counts of *saengshik* products of different manufacturing companies available in the Korean market. Values with different small letters (a–d) within the same bar are significantly different at $p < 0.05$. ND, not detected (detection limit < 10 CFU/g)

cereus was detected only in sample SP-5 (Table 1). The microbiological standards and specifications of *saengshik* classes established by the Korean Food Standards Codex [3] recommends no detection of *E. coli* and populations levels of $< 10^2$ CFU/g for *C. perfringens*, and $< 10^3$ CFU/g for *B. cereus*. The experimental data clearly indicated that *saengshik* products from some companies available in the Korean market were not microbiologically safe for human consumption. Microbial contamination of *saengshik* products might have occurred through the inclusion of one or more contaminated raw ingredient or during the actual processing of *saengshik* in the mixing rooms. *Saengshik* manufacturing companies are legally responsible to ensure that their products are not contaminated with harmful microorganisms and are therefore safe for human consumption. Hence, there is a need to adopt an improved manufacturing process to enhance the microbiological safety of *saengshik*. For example, the washing of raw materials with electrolyzed water and ozonated water has been suggested to reduce pathogenic bacteria in *saengshik* [8].

Kim et al. [24] investigated the microbial contamination of 230 food products, including cereal-based infant formulas, available in the Korean market. The data showed that some of these food products contained a high level of aerobic plate counts and were also positive for coliforms. *B. cereus* was detected in 48 samples (20.9%), while *Cronobacter* spp. was isolated from 10 samples (4.4%). The authors suggested the need to adopt hygienic control measures to improve the safety of these food products.

DEFT/APC results

The DEFT method calculates the total number of contaminating microorganisms in a food sample, irrespective of their viability. The APC method, on the other hand, enumerates the number of viable microorganisms; i.e., those that can form colonies on an agar plate. The DEFT/APC method, therefore, represents the microbial decontamination of a sample after some previous treatment. When no decontamination treatment is applied, the DEFT

counts should be similar to the APC counts because viable microbial cells would be present in the sample. Conversely, the APC counts will be considerably less than the DEFT counts if a decontamination treatment has been used; for example, irradiation processing. A limitation of the method is encountered when there are too few microbes in the sample. In addition, when other treatments, such as heat or chemicals, have been used for decontamination, a similar difference in microbial counts is possible to that obtained by irradiation. Thus, a reduction of viable microbial counts in irradiated foods could only be a potential screening parameter [13, 20, 25].

The results of the DEFT/APC analysis of commercial *saengshik* products are provided in Table 2. The APC counts of three samples, SP-2, SP-8, and SP-12, were considerably lower than the DEFT counts, resulting in DEFT/APC ratios of 3.54, 4.10, and 3.86, respectively. The difference between the DEFT and APC counts is generally 3–4 log units for samples subjected to irradiation treatment. In addition, a DEFT/APC ratio of more than 4.0 indicates the irradiation-based decontamination of a sample. Thus, the difference in APC and DEFT counts and DEFT/APC ratios suggested the irradiation-based decontamination of these three samples. In addition, for the corresponding 1 kGy-irradiated *saengshik* samples, the difference between the DEFT and APC counts was very high because the microorganisms were inactivated by the irradiation treatment (Table 2). The successful application of the DEFT/APC method has also been reported for the screening of irradiated spices [23] and frozen crushed garlic [25]. The method provided a clear screening of gamma-irradiated cinnamon, red pepper, black pepper, and fresh paprika samples [16]. However, the DEFT/APC method is not radiation-specific and confirmation of a positive result is recommended using a standardized method [13, 20, 25].

PSL screening results

PSL analysis was first proposed by Sanderson [26] to discriminate between non-irradiated and irradiated food

Table 1 Detection of foodborne pathogenic bacteria in *saengshik* products from the Korean market

Pathogen	Saengshik samples											
	SP-1	SP-2	SP-3	SP-4	SP-5	SP-6	SP-7	SP-8	SP-9	SP-10	SP-11	SP-12
<i>Clostridium perfringens</i>	- ^a	–	–	–	–	–	+ ^b	–	+	–	–	–
<i>Bacillus cereus</i>	–	–	–	–	+	–	–	–	–	–	–	–
<i>Escherichia coli</i>	–	–	–	+	+	–	–	–	+	–	–	–

^aNegative

^bPositive

Table 2 DEFT/APC counts of commercial *saengshik* products

Sample	Commercial samples (log CFU/g)			1 kGy-irradiated samples		
	DEFT	APC	DEFT/APC ratio ^a	DEFT	APC	DEFT/APC ratio
SP-1	8.01	5.20	1.54	9.45	3.33	2.84
SP-2	9.42	2.66	3.54	8.15	2.08	3.92
SP-3	8.96	5.60	1.60	9.21	2.16	4.26
SP-4	8.45	7.48	1.13	8.30	4.15	2.00
SP-5	8.39	5.45	1.54	8.21	2.08	3.95
SP-6	7.67	5.81	1.32	9.01	3.98	2.26
SP-7	6.10	5.75	1.06	7.84	3.60	2.18
SP-8	10.50	2.56	4.10	9.35	1.44	6.49
SP-9	6.55	5.90	1.11	7.98	3.03	2.63
SP-10	9.96	7.97	1.25	9.85	4.88	2.02
SP-11	5.96	5.18	1.15	5.75	3.15	1.83
SP-12	9.30	2.41	3.86	9.09	1.86	4.89

^aDEFT/APC ratio ≥ 4.0 indicates irradiation-based decontamination of the sample

samples. Over the years, the PSL technique has gained popularity as a simple and rapid screening approach without the need for any complicated sample pre-treatment [11, 14, 16, 18, 20, 27]. Light is used in the PSL technique instead of heat for stimulation of electromagnetic emission from irradiated mineral debris, typically the silicates. PCs for all samples are shown in Table 3. Three samples, SP-2, SP-8, and SP-12, suspected of being irradiated according to the DEFT/APC method, presented PCs in the positive PSL range (> 5000 counts/60 s), and thus were easily screened out as irradiated samples. By contrast, the remaining nine samples were in the negative PSL range (< 700 counts/60 s).

The presence of a low quantity of minerals in food samples and insensitivity to light stimulation could lead to a poor PSL output [14]. Therefore, PSL signals below the lower threshold (T_1) can also result from low sensitivity of the irradiated materials. It is recommended that calibrated PSL measurements must be performed in order to avert false negative results. Negative calibrated PSL results serve as indicators of insufficient PSL sensitivity caused by low mineral content. If the calibrated PSL signals were generated in higher proportion as compared to their corresponding negative results, this demonstrates possibly the non-irradiated status of the samples. If the order of the magnitude of the positive calibrated PSL results are lying

Table 3 PSL results of commercial *saengshik* products: initial, second measured, and index sensitivity

Sample	Initial PSL (1st measured)	Calibrated PSL ^a (2nd measured)	Index sensitivity ^b
SP-1	461 $\pm$ 71 ^c (−) ^d	52,1101 $\pm$ 274,500(+)	1129 ^e
SP-2	57125 $\pm$ 49(+)	107,352 $\pm$ 26,474(+)	1.88
SP-3	364 $\pm$ 199(−)	4,294,001 $\pm$ 587,854(+)	11,796
SP-4	567 $\pm$ 99(−)	9454 $\pm$ 561(+)	16.00
SP-5	482 $\pm$ 96(−)	64,394 $\pm$ 40,543(+)	133
SP-6	141 $\pm$ 289(−)	5,856,422 $\pm$ 1,688,166(+)	41,534
SP-7	366 $\pm$ 53(−)	130,856 $\pm$ 32,409(+)	357
SP-8	1,434,823 $\pm$ 49,547(+)	3,226,985 $\pm$ 1,445,553(+)	2.00
SP-9	435 $\pm$ 34(−)	41,761 $\pm$ 15,654(+)	96.00
SP-10	481 $\pm$ 143(−)	14,481 $\pm$ 3457(+)	30.00
SP-11	285 $\pm$ 143(−)	59,277 $\pm$ 30,188(+)	207
SP-12	3,564,680 $\pm$ 35,362(+)	5,904,527 $\pm$ 2,229,829(+)	1.70

^aPSL photon counts per 60 s after irradiation with calibration dose of 1 kGy

^bIndex sensitivity = calibrated PSL value/initial PSL value

^cMean $\pm$ standard deviation ($n = 10$)

^dThreshold value: $T_1 = 700$, $T_2 = 5,000$, (−) $< T_1$, $T_1 < (M) < T_2$, (+) $> T_2$

^eIndex sensitivity > 10.00 : non-irradiated, index sensitivity < 10.00 : irradiated

within the same order as that of screening results, then it was inferred that samples are exposed to irradiation treatment. Positive calibrated PSL results within the same order of magnitude as the screening results are indicative of irradiation treatment. The calibrated PSL signals for all samples were substantially high and exceeded the upper threshold ($> T_2$), which confirmed the presence of a sufficient amount of mineral debris in the commercial *saengshik* products. Furthermore, sensitivity was calculated in terms of index by calculating the ratio of calibrated PSL and initial PSL signals. Three samples, SP-2, SP-8, and SP-12, had an index of sensitivity of less than 10, thereby easily classifying them as irradiated samples (Table 3).

The detection of an irradiated component in blended products, particularly when present at a low concentration, could be more challenging for all detection methods, including the PSL technique. Akram et al. [17] evaluated the applicability of PSL to detect irradiated components in non-irradiated mushroom powders. The PSL results were negative for all blend samples at the lowest 1% mixing ratio, whereas intermediate results were obtained for samples containing a relatively higher 5% or 10% of the irradiated component. Only the sample mixtures containing 10% of high dose (10 kGy) irradiated component produced positive PSL results. *Saengshik* is a blended product, it is therefore possible that the final product may contain one or more irradiated raw ingredients at various concentrations. In another study, PSL discriminated between irradiated and non-irradiated cinnamon and red pepper powders; however, black pepper powder presented intermediate PSL counts [16]. Hence, the PSL results should be validated using a more validated technique [16, 18, 19, 25, 27].

TL confirmatory analysis results

TL analysis was performed to confirm the irradiation status of the *saengshik* products. TL glow curves of isolated minerals are shown in Fig. 2. The separated minerals from samples SP-2, SP-8, and SP-12 produced a typical first TL glow curve (TL_1) with maximum peak at a temperature range of 150–200 °C. By contrast, the minerals from the other samples produced a weak TL glow curve with high intensity above 300 °C (Fig. 2). Minerals isolated from irradiated foodstuffs usually produce a glow curve peak in the temperature range of 150–250 °C, whereas low natural radioactivity produces TL signals above 300 °C in non-irradiated samples [15]. The second TL glow (TL_2) was obtained after a subsequent exposure of the already measured minerals on TL discs to a fixed radiation dose of 1 kGy, applied for the purpose of normalization [15]. The TL ratio (TL_1/TL_2) was calculated to confirm the authenticity of the minerals on the TL disks. Three samples, SP-2, SP-8, and SP-12, which were screened as irradiated by the

PSL and DEFT/APC techniques, provided a TL ratio of more than 0.1, thus confirming the irradiated status of these samples (Table 4). These findings are in good agreement with the results of other studies. A number of studies have reported the potential of TL as a confirmatory technique for the authentic identification of a wide variety of irradiated foodstuffs, such as dried red peppers, chilli, black peppers, and black tea [18], radiation and grinding-induced luminescence properties in wheat flour [19], fresh mushrooms [27], different types of sauces [28], and electron beam and gamma-irradiated frozen crushed garlic samples from China and Korea [25]. Low quantities of irradiated component were also reported to be detected in non-irradiated powders [17]. Gamma-irradiated mushroom in low quantity was mixed with non-irradiated mushroom powder in ratio of 1–10%. The detection in blended samples was possible even at 1% addition of 2 kGy-irradiated powder, by characterizing the TL glow curves with respect to shape and intensity [17].

Food irradiation has been widely studied to improve the microbial safety of food products [10]. In the present study, the three *saengshik* samples that were confirmed as irradiated by the applied techniques (DEFT/APC, PSL, and TL) were negative for *C. perfringens*, *E. coli* O157:H7, and *B. cereus*, clearly indicating the potential of irradiation processing in reducing foodborne pathogenic bacteria in such food products. International organizations, such as the IAEA, WHO, FAO, IFT, EFSA and many others have declared food irradiation is a favorable option to ensure food safety without any danger associated with the consumption of these irradiated foods [12, 29]. In recent years, the quantity of irradiated foods has significantly increased in Asia and the United States; however, it has decreased in the European Union [30]. The application of irradiation technology is still limited on a commercial scale because of an asserted negative public perception. Furthermore, regulatory authorities around the world require proper labeling of irradiated foods, and the irradiation treatment must be carried out at accredited facilities [10]. Nevertheless, a huge quantity of irradiated foodstuffs enter into the European Union market without having the “Radura” mark or printed with words such as, “treated with irradiation” [12]. In Italy, an accredited laboratory carried out analytical controls on 451 different foodstuff samples during period of 2006–2011. Four different approaches for screening and confirmatory purposes were employed: PSL, DNA comet assay, TL, and electron spin resonance (ESR) spectroscopy [12]. Eighteen samples demonstrated non-compliance and these non-compliances comprised both incorrect labeling and the irradiation processing taking place in approved facilities of European or third-world countries. In China, the irradiation status of 133 commercial food samples, including spices, dehydrated vegetables, and fruit, was

Fig. 2 TL glow curves of minerals isolated from commercial *saengshik* products, and after 1 kGy-irradiation for normalization

investigated using the TL method, and 30 samples (22.6%) were proved to be irradiated [31]. In present study, the *saengshik* samples SP-2, SP-8, and SP-12 from three different manufacturing companies available in the local markets of Korea were confirmed as irradiated but were non-compliant with the mandatory labeling requirements.

In conclusion, some *saengshik* products commercially available in the Korean market contained a high level of total plate counts, yeasts and molds, and coliforms. Food-borne pathogenic bacteria including *E. coli* O157:H7, *C. perfringens*, and *B. cereus* were detected from four products. The PSL and TL techniques effectively identified the

Fig. 2 continued

Table 4 TL glow curves (TL_1/TL_2) intensity of minerals isolated from *saengshik* products

Sample	Commercial samples			1 kGy-irradiated samples		
	TL_1^a (nC)	TL_2^b (nC)	TL ratio ^c	TL_1^a (nC)	TL_2^b (nC)	TL ratio ^c
SP-1	14.3	1680	0.008(−)	4571	6793	0.673(+)
SP-2	6011	10,090	0.576(+)	14,560	9131	1.597(+)
SP-3	5.9	3785	0.001(−)	3162	3528	0.896(+)
SP-4	2.4	4893	0.001(−)	588.4	1104	0.533(+)
SP-5	8.3	7594	0.001(−)	5541	3732	1.484(+)
SP-6	13	4453	0.003(−)	5239	4855	1.079(+)
SP-7	5.8	4849	0.001(−)	11,110	10,070	1.103(+)
SP-8	1881	1190	1.580(+)	3693	2867	1.288(+)
SP-9	3.1	7626	0.001(−)	1060	836.9	1.267(+)
SP-10	12.2	1190	0.010(−)	2158	646.1	3.340(+)
SP-11	128	57,540	0.002(−)	12,330	18,640	0.661(+)
SP-12	28,660	41,480	0.691(+)	68,170	59,860	1.139(+)

^aIntegrated TL_1 intensity at 150–250 °C^bIntegrated TL_2 intensity at 150–250 °C^cTL ratio (TL_1 intensity/ TL_2 intensity), < 0.1: non-irradiated(−), TL ratio > 0.1: irradiated(+)

irradiation status of all samples. Three of the twelve samples were identified as being irradiated without any statements on treatment. Proper labeling or statements of irradiated food will provide the consumer with its free choice. No heat treatment is used for manufacturing of *saengshik* products. Irradiation of raw materials like cereals, legumes, and their powders with gamma ray and electron beam is currently permitted by the Ministry of

Food and Drug Safety (MFDS), which can be an effective intervention strategy for securing the microbial safety in *saengshik* products in compliance with existing labeling regulations [3].

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Compliance to ethical standards

Conflict of interest The authors have no conflict of interest to declare.

References

- Kim D, Song S, Kang W, Jeong YH, Yoon Y, Lee Y, Chang B, Lee K. Superfine *Saengshik* improves liver protecting effect compared with fine *Sanengshik* in an animal model. *J. Food Sci.* 74: 59–64 (2009)
- Kim HY, Kim JH, Lee SA, Chang HE, Park MH, Hwang SJ, Lee JY, Mok C, Hong SG. *Saengshik*, a formulated health food, prevents liver damage in CCl₄-induced mice and increases antioxidant activity in elderly women. *J. Med. Food* 11: 323–330 (2008)
- Korean Food Standards Codex. Ministry of Food and Drug Safety (MFDS). Osong-eup, Korea. pp 5–29–25 (2014). Available online: http://www.foodsafetykorea.go.kr/foodcode/03_02.jsp?idx=96
- Kim M, Kim E, Kwak HS, Jeong Y. The ingredients in *Saengshik*, a formulated health food, inhibited the activity of α -amylase and α -glucosidase as anti-diabetic function. *Nutr. Res. Prac.* 8: 602–606 (2014)
- Lee SA, Kim JH, Kim WY, Hwang SJ, Park MH. *Saengshik* administration reduced the side effects of chemotherapy in chemotherapeutic agent injected mice. *Cancer Prev. Res.* 12: 319–328 (2007)
- Cho JI, Park Y, Ko SI, Cheung C, Lee S, Cho S, Lee K, Lim C, Kim OH. Investigation of pathogenic microorganism from saengsik-classes. *J. Food Hyg. Safety* 23: 257–263 (2008)
- Kwak HS, Whang I, Park JS, Kim MG, Lee KY, Gho YH, Bae YY, Moon SY, Byun JS, Kwon KS, Woo GJ. Quantitative evaluation of foodborne pathogenic bacteria in commercial *Saengshik*. *J. Food Hyg. Safety* 21: 41–46 (2006)
- Chang TE, Han JS, Song OJ, Chung DH, Shin IS. Study on reducing methods of natural food-borne pathogenic microorganisms originated from *Saengshik*. *Korean J. Food Sci. Technol.* 6: 1020–1025 (2004)
- Korean Food Standards Codex. Ministry of Food and Drug Safety (MFDS). Osong-eup, Korea. pp 2–10 ~ 2–11 (2014) Available online: http://www.foodsafetykorea.go.kr/foodcode/01_03.jsp?idx=12
- Farkas J, Mohacsi-Farkas C. History and future of food irradiation. *Trends Food Sci. Tech.* 22: 121–126 (2011)
- Arvanitoyannis IS. Irradiation detection. pp. 67–139 In: *Irradiation of Food Commodities: Techniques, Applications, Legislation, Safety and Consumer Opinion*. Academic Press Publications: London (2010)
- Mangiacotti M, Marchesani G, Floridi F, Siragusa G, Chiaravalle AE. Official checks by an accredited laboratory on irradiated foods at an Italian market. *Food Control* 33: 307–312 (2013)
- Stefanova R, Vasilev NV, Spassov SL. Irradiation of food, current legislation framework, and detection of irradiated foods. *Food Anal. Methods* 3: 225–252 (2010)
- EN 13751. Foodstuffs–detection of irradiated food using photo-stimulated luminescence. European Committee of Standardization (CEN), Brussels, Belgium (2009)
- EN 1788. Foodstuffs–detection of irradiated food from which silicate minerals can be isolated: Method by thermoluminescence. European Committee of Standardization (CEN), Brussels, Belgium (2001)
- Ahn JJ, Akram K, Kwak JY, Jeong MS, Kwon JH. Reliable screening of various foodstuffs with respect to their irradiation status: A comparative study of different analytical techniques. *Radiat. Phys. Chem.* 91: 186–192 (2013)
- Akram K, Ahn J, Shahbaz HM, Jo D, Kwon JH. Effectiveness of thermoluminescence analysis to detect low quantity of gamma-irradiated component in non-irradiated mushroom powders. *J. Lumin.* 136: 395–400 (2013)
- Bayram G, Delincée H. Identification of irradiated Turkish foodstuffs combining various physical detection methods. *Food Control* 15: 81–91 (2004)
- Shahbaz HM, Akram K, Ahn JJ, Kwon JH. Radiation- and grinding-induced luminescence properties for the detection of irradiated wheat. *J. Cereal Sci.* 57: 261–263 (2013)
- Shahbaz HM, Ahn JJ, Akram K, Kwon JH. Screening methods for the identification of irradiated foods. *Curr. Res. Agric. Life Sci.* 31: 1–10 (2013)
- Korean Food Standards Codex. Ministry of Food and Drug Safety (MFDS). Osong-eup, Korea. pp 9–3–27 ~ 9–3–45 (2014) Available online: http://www.foodsafetykorea.go.kr/foodcode/01_02.jsp?idx=263
- EN 13783. Detection of irradiated food using Direct Epifluorescent Filter Technique/Aerobic Plate Count (DEFT/APC) screening method. Committee European Normalization (CEN), Brussels, Belgium (2001)
- Oh KN, Lee SY, Lee HJ, Kim KE, Yang JS. Screening of gamma irradiated spices in Korea by using a microbiological method (DEFT/APC). *Food Control* 14: 489–494 (2003)
- Kim SA, Oh SW, Lee YM, Imm JY, Hwang IG, Kang DH, Rhee MS. Microbial contamination of food products consumed by infants and babies in Korea. *Lett. Appl. Microbiol.* 53: 532–538 (2011)
- Kim HY, Ahn JJ, Shahbaz HM, Park KH, Kwon JH. Physical-, chemical-, and microbiological-based identification of electron beam- and γ -irradiated frozen crushed garlic. *J. Agric. Food Chem.* 62: 7920–7926 (2014)
- Sanderson DCW. Photostimulated luminescence (PSL): A new approach to identifying irradiated foods. pp. 159–167. In: Raffi, J. (Ed.), *Potential New Methods of Detection of Irradiated Food*. European Commission Report, Luxembourg (1991)
- Akram K, Ahn JJ, Kim GR, Kwon JH. Applicability of different analytical methods for the identification of γ -irradiated fresh mushrooms during storage. *Food Sci. Biotechnol.* 21: 573–579 (2012)
- Akram K, Ahn JJ, Yoon SR, Kwon JH. Effect of γ -irradiation on physical quality attributes and identification properties of different sauces. *Food Sci. Biotechnol.* 21: 1173–1178 (2012)
- European Food Safety Authority (EFSA). Statement summarizing the conclusion and recommendations from the opinions on the safety of irradiation of food adopted by the BIOHAZ and CEF panels. *EFSA J.* 9(4), 2107 (2011)
- Kume T, Todoriki S. Food irradiation in Asia, the European Union, and the United States: A status update. *Radioisotopes* 62: 291–299 (2013)
- Chen SQ, Jiang KX, Cao BS, Liu YQ, Cai XF, Liu XL, Cao Y, Liu XY, Shi WN. Distribution of irradiated foods in China. *Food Control* 28: 237–239 (2012)