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Article

Inactivation of *Agrobacterium tumefaciens* Inoculated on Fresh Radix Ginseng by Electron Beam Irradiation and Aqueous Chlorine Dioxide Treatment

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Inactivation of *Agrobacterium tumefaciens* was evaluated on the inoculated fresh Radix Ginseng by electron beam irradiation or aqueous chlorine dioxide (ClO_2) treatment. Two groups of fresh ginsengs were prepared and inoculated with *A. tumefaciens*. One group was then irradiated at 0, 2, and 4 kGy using an electron beam accelerator, and the other group was treated with 0, 50, and 100 ppm of aqueous ClO_2. Microbiological data indicated that populations of *A. tumefaciens* significantly decreased with increasing irradiation dose or aqueous ClO_2 concentration. In particular, *A. tumefaciens* was eliminated by irradiation at 4 kGy, and 100 ppm ClO_2 treatment reduced the populations of *A. tumefaciens* by 1.44 log CFU/g. These results suggest that electron beam irradiation or aqueous ClO_2 treatment can be useful in improving the microbial safety of fresh ginsengs during storage.

Key words: Agrobacterium tumefaciens, *aqueous chlorine dioxide, electron beam irradiation, microbial growth*

Medicinal herbs have been widely used as the major source of phytochemicals and functional health foods [Soriani *et al.*, 2005], among which Radix Ginseng (*Panax ginseng* C.A. Meyer) has been used as one of the most important medicinal herbs for a long time in Asia [Jin *et al.*, 2007]. Fresh ginsengs are generally cultivated for 4 to 6 years and harvested from August through October. However, after harvest fresh ginsengs deteriorate within a week, because they contain about 75% moisture [Ha *et al.*, 2004]. Therefore, it is difficult to maintain high-quality fresh ginsengs year-round. Moreover, harvested fresh ginsengs are easily spoiled by plant pathogens attached to the ginsengs during harvest. Deterioration of the fresh ginsengs is generally associated with red-coloring phenomenom and mold growth [Hu *et al.*, 2004]. In particular, microbial contamination, dehydration, and physicochemical changes accelerate the deterioration of fresh ginsengs [Jeon and Lee, 1999].

Agrobacterium tumefaciens is one of the most detrimental soil-borne plant pathogens that cause the red-coloring phenomenon of *P. ginseng* [Park *et al.*, 2006]. The red-coloring phenomenon is characterized by the development of a reddish brown to orange brown color on the fresh ginseng surface, followed by blistering of the affected tissues. *A. tumefaciens* is also the causative agent of crown gall disease, which is a tumor of the tissue bulging from stems and roots of woody and herbaceous plants [Jia *et al.*, 2002]. Plant pathogenic microorganisms in the fresh ginsengs make the surfaces of the fresh ginsengs rough and red-colored, resulting in poor quality fresh ginsengs. Therefore, microbial decontamination of the fresh ginsengs is needed.

Food irradiation is a well-established method, but it received less attention in fresh medicinal herbs [Razem and Katusin-Razem, 2002]. Food irradiation is recognized as an effective method to provide hygienic quality by reducing the quality loss due to the microbial spoilage. There are two most common types of ionizing radiation; gamma ray and electron beam. Electron beam has a shorter processing time and does not produce radioactive wastes [Black and Jaczynski, 2006]. Therefore, electron beam irradiation is appropriate for microbial decontamination of the medicinal herbs. Jin *et al.* [2007] reported that electron beam irradiation could be useful in improving the microbial safety of Korean ginseng.

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Abbreviations: CFU, colony forming unit

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Chlorine has been used as a typical sanitizer in the food industry, but there have been some health concerns due to the presence of trihalomethanes and chlorophenols generated during chlorination [Kim *et al.*, 1999]. Therefore, many studies have been performed on chlorine dioxide (ClO_2) as an effective alternative to chlorine [Owusu-Yaw *et al.*, 1990]. Aqueous ClO_2 treatment has been commercially used in the food industries for apple packing and chicken processing, among others. Tsai *et al.* [2001] reported that aqueous ClO_2 treatment was effective against the microorganisms on potatoes. Bae and Lee [1999] also reported that ClO_2 treatment effectively reduced the major pathogenic bacteria such as *Vibrio anguillarum, Edwardsiella tarda,* and *Streptococcus sp.* in flounder. Therefore, the objective of this study was to determine the effect of electron beam and aqueous ClO_2 on the inactivation of the pathogenic *A. tumefaciens* on fresh ginsengs during storage.

Materials and Methods

Preparation of fresh ginseng samples. Fresh Radix Ginseng (4 years old, harvested in 2007) were purchased from Geumsan Ginseng Center (Geumsan, Korea). They were rinsed with tap water for 10 min and used for electron beam irradiation or aqueous ClO_2 treatment.

Bacterial strain and culture preparation. *Agrobacterium tumefaciens* (ATCC 11157) cultures were grown at 26°C for 24 h in 50-mL tubes containing 25 mL nutrient broth (Difco, Detroit, MI).

Inoculation. Fresh ginseng samples were treated with UV light in a clean bench for 30 min (15 min each on both sides) to reduce the population of preexisting microorganisms. Harvested bacterial cell cultures were centrifuged (3000×*g* at 4°C for 15 min), and the cultures were washed twice with sterile 0.1% peptone water. Inoculation solution of *A. tumefaciens* was prepared by diluting in distilled water at a 7 log CFU/mL. The samples were dipped in a bacterial inoculum solution at the ratio of 1:10 (w/v). They were agitated by stirring with a glove-covered hand for 30 min. The inoculated fresh ginseng samples were then air-dried in a clean bench for 30 min.

Electron beam irradiation. Electron beam irradiation was performed using an electron-beam accelerator (Model ELV-8, 2.5 MeV, Eb-Tech, Daejeon, Korea). Samples (intact at purchase; thickness, 12~15 mm; 15 g each) were individually packaged in 120 mm×60 mm low density polyethylene bags (thickness, 0.1 mm). Based on the preliminary experiment, samples were exposed to 2, 4, 6, 8, and 10 kGy at 2.5 MeV (6.0 mA, beam dimension 600 mm×600 mm, velocity 20 m/min). The absorption dose was determined using a cellulose triacetate dosimeter. After irradiation, the samples were stored at 4±1°C for 8 days.

Aqueous chlorine dioxide treatment. Aqueous ClO_2 was prepared using a ClO_2-generating system (CH_2O Inc., Olympia, WA) as described previously [Youm *et al.*, 2004]. The samples were treated by dipping in a solution of 0, 50, and 100 ppm ClO_2 solution for 30 min. After ClO_2 treatment, the samples were individually packaged and stored at 4±1°C for 8 days.

Microbiological analysis. After electron beam irradiation or ClO_2 treatment, 15 g fresh ginsengs were placed in 135 mL of peptone water (0.1% sterile peptone, w/v) in a sterile stomacher bag. They were then homogenized using a stomacher (MIX 2, AES Laboratoire, Combourg, France) for 6 min, filtered through a sterile cheese cloth, and diluted with peptone water for microbial count. Serial dilutions were performed in triplicates. *A. tumefaciens* counts were determined by plating the appropriately diluted samples onto to the nutrient agar (Difco). The plates were incubated at 26°C for 48 h. During storage at 4°C, the change in the populations of *A. tumefaciens* was determined. Each microbial count was the mean of three determinations and expressed as log CFU/g.

Weight loss. Weight losses during storage were determined by weighing the initial and the final weights of the samples. The values were expressed as relative percentages.

Color measurement. Colors of the samples were analyzed using a colorimeter (CR-300 Minolta Chroma Meter, Minolta Camera Co., Osaka, Japan). The samples were placed on a white standard plate, and Hunter's color values (L, a, and b) were measured. Light source was a standard illuminant C, and the observer was 2 degree. Aperture size was 1.7 cm. Hunter's L, a, and b values for the standard plate were L = 98.34, a = -0.03, and b = 1.62.

Sensory evaluation. The color, odor, and overall acceptability of the samples were analyzed by eight trained panelists (four each men and women; age range, 22 to 27). Sensory qualities of the samples were evaluated using the five-point scoring method. Sensory scores were: 5, very good; 4, good; 3, fair; 2, poor; and 1, very poor [Kwon *et al.*, 2000].

Statistical analysis. Analysis of variance and Duncan's multiple range tests with significance at $p<0.05$ were performed using an SAS program (SAS Inst. Version 8.2, 2001). Each microbial count was the average of three determinations. Five and three replications were performed for color measurement and weight loss, respectively.

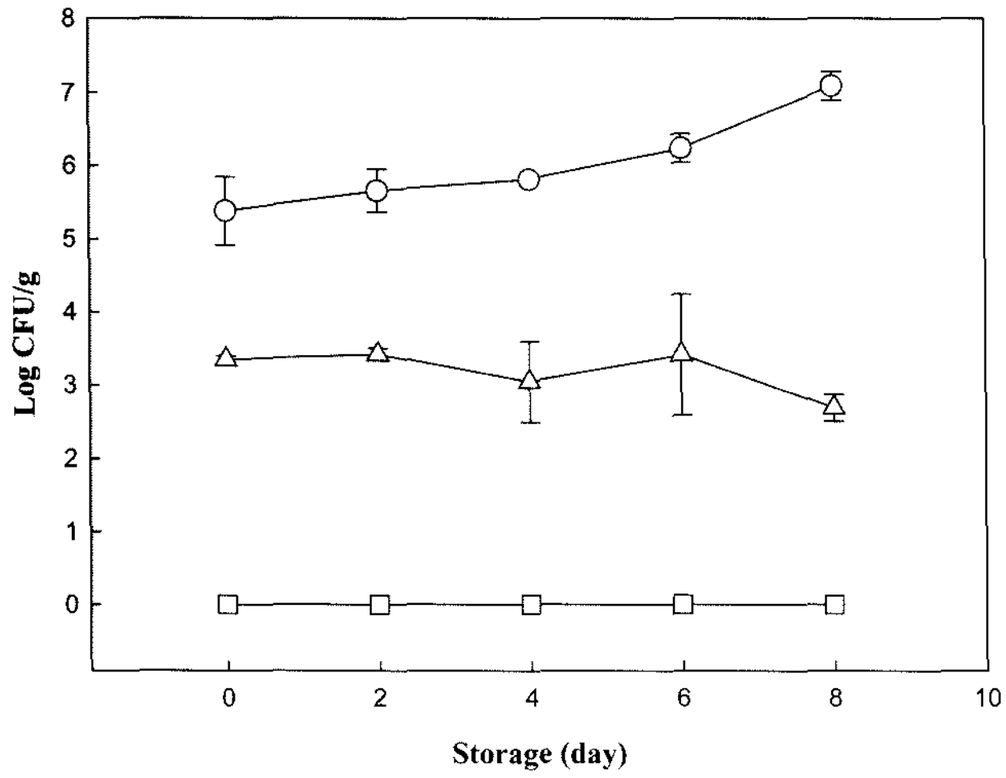

Fig. 1. Effects of electron beam irradiation on the survival of *A. tumefaciens* inoculated on to fresh ginseng. ○: 0 kGy, △: 2 kGy, □: 4 kGy.

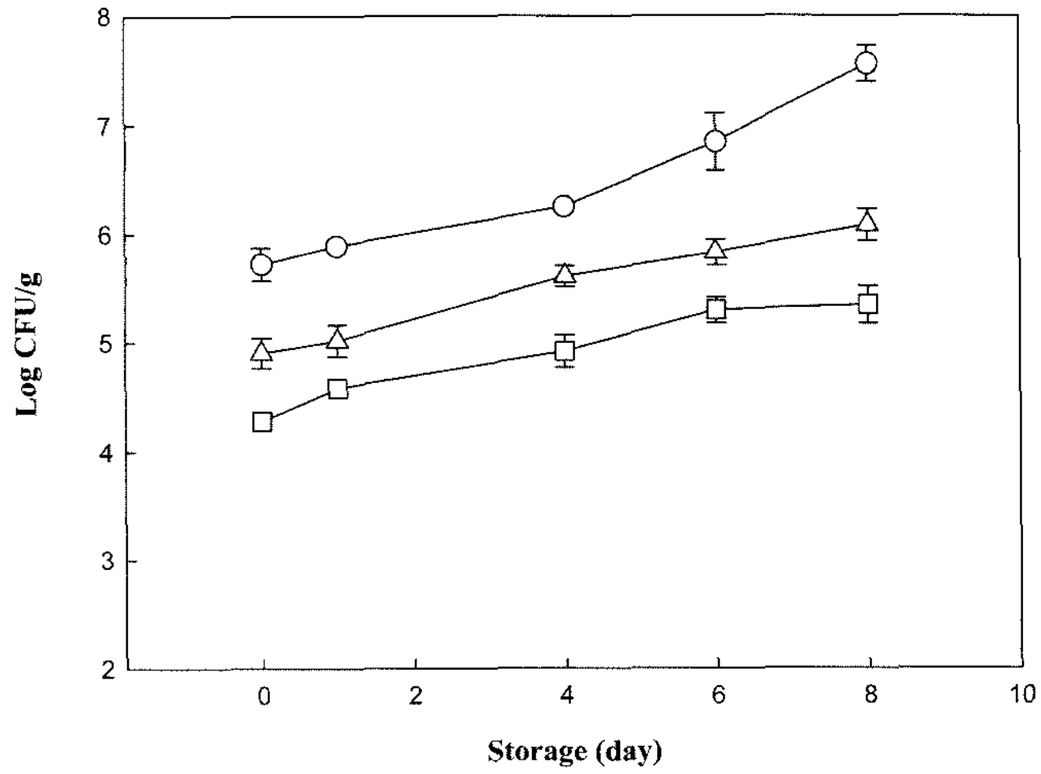

Fig. 2. Effects of ClO_2 treatment on the survival of *A. tumefaciens* inoculated on to fresh ginseng. ○: control, △: 50 ppm, □: 100 ppm.

Results and Discussion

Increase in the dose of electron beam irradiation decreased the population of *A. tumefaciens*; above 4 kGy the population was eradicated (Fig. 1). Population of *A. tumefaciens* treated at 2 kGy decreased to 3.35 log CFU/g, compared to 5.38 log CFU/g of the non-irradiated sample. On the other hand, populations of *A. tumefaciens* for the non-irradiated sample increased to 7.09 log CFU/g after 8 d of storage, whereas that of the irradiated sample decreased to 2.69 log CFU/g at 2 kGy. Only a few studies have been reported on the effect of ionizing irradiation on ginsengs. Jin *et al.* [2007] reported the effect of electron beam irradiation on Korean ginseng, in which the treatment at 8 kGy resulted in 2.5 log cycle reductions in yeast and mold. Kwon *et al.* [2000] also reported that gamma irradiation at 5 kGy decreased the number of total bacteria in ginseng powder by more than 3 log CFU/g. These reports are consistent with our results. FAO/IAEA/WHO Expert Committee on food irradiation (JECFI) recommends 10 kGy as the upper dose limit for safe food irradiation processes, indicating that there is no toxicological evidence at this dose. Results of the present study showed that electron beam irradiation at 2 kGy decreased the *A. tumefaciens* count in ginseng during storage up to 8 d by 2.0-4.4 log cycles and treatment above 4 kGy eradicated the microorganism.

Aqueous ClO_2 treatment significantly decreased the microbial populations in *A. tumefaciens*, as compared to the control. After the ClO_2 treatment, populations of *A. tumefaciens* in the inoculated fresh ginseng were 5.72, 4.90, and 4.28 log CFU/g after 0, 50, and 100 ppm ClO_2 treatment, respectively (Fig. 2). In particular, 100 ppm ClO_2 treatment reduced *A. tumefaciens* by 1.44 log CFU/g, compared to that of the control. After 8 d of storage, the control reached 7.56 log CFU/g, whereas the populations of *A. tumefaciens* for the samples treated with 50 and 100 ppm of ClO_2 showed 6.08 and 5.35 log CFU/g, respectively. Lee *et al.* [2004] reported that 40 ppm treatment of ClO_2 in apple decreased *Alicyclobaillus acidoterrestris* spore count by more than 4 log CFU/g. Wu and Kim [2007] also reported that the treatment of 15 ppm ClO_2 in blueberries decreased yeast and mold counts by 2.86 log cycle. Results of the present study suggest that aqueous ClO_2 treatment could decrease the population of *A. tumefaciens* in the fresh ginseng, and 100 ppm ClO_2 treatment can extend the shelf life by inhibiting the growth of the microorganisms.

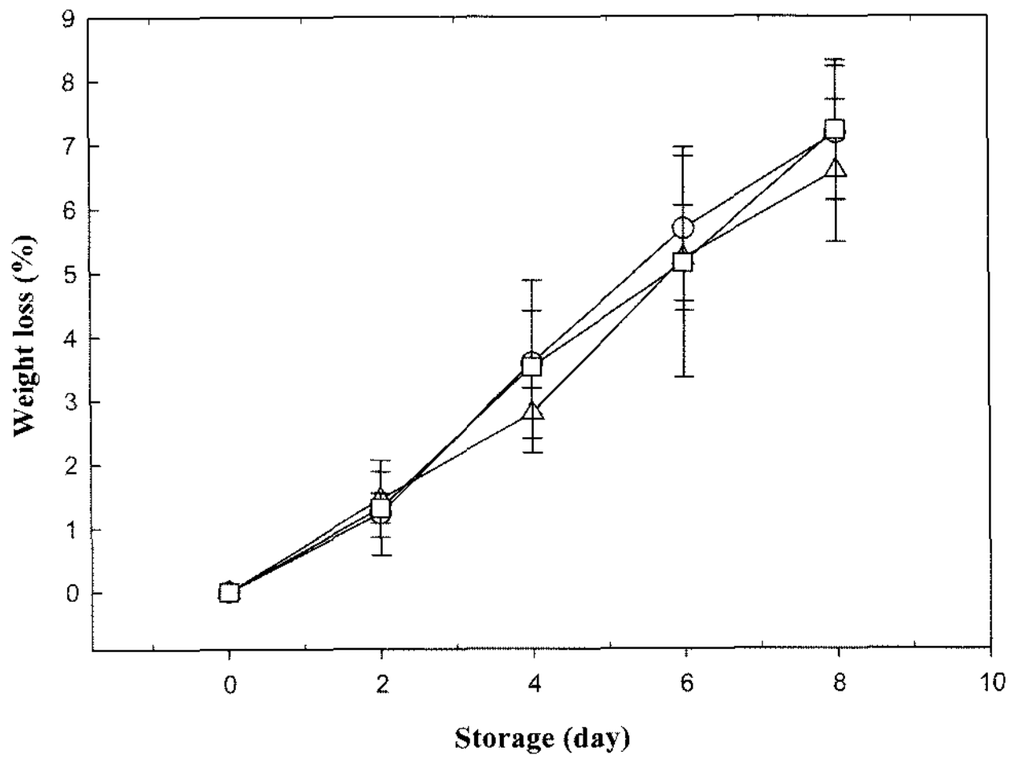

Fig. 3. Changes in weight loss of electron beam-irradiated fresh ginseng during storage. ○: 0 kGy, △: 2 kGy, □: 4 kGy.

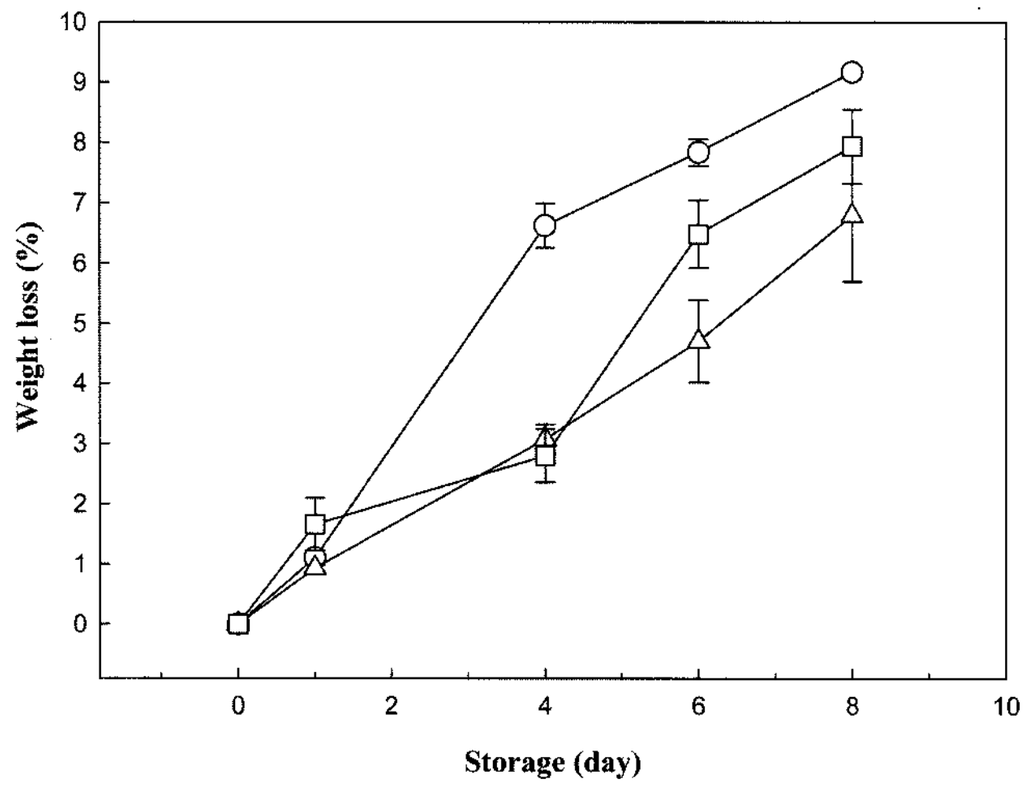

Fig. 4. Changes in weight loss of ClO_2-treated fresh ginseng during storage. ○: control, △: 50 ppm, □: 100 ppm.

The weight loss of the fresh ginseng increased by 6.6~9.2% after 8 days of storage (Figs. 3 and 4). For electron beam irradiation, weight loss of the fresh ginseng after 8 days of storage was 7.17, 6.58, and 7.22% at 0, 2, and 4 kGy irradiation, respectively, indicating that there was no significant difference among doses. These results are consistent with the report of Miller *et al.* [1994], in which electron beam irradiation did not affect the weight loss of blueberries during storage. However, for aqueous ClO_2 treatment, weight loss of the fresh ginseng after 8 d of storage was 9.17, 6.80, and 7.94% at 0, 50, and 100 ppm treatments, respectively, indicating that ClO_2 treatment deterred the weight loss. These results are comparable with those of a previous study [Ku *et al.*, 2006].

Hunter L, a, and b values of the fresh ginseng showed significant differences among treatments during storage (Tables 1 and 2). In particular, after 4 days of storage,

Table 1. Changes in Hunter color values of electron beam-irradiated fresh ginseng during storage at 4°C

Color parameter	Irradiation dose (kGy)	Storage period (day)				
		0	2	4	6	8
L	0	83.00±1.16[a]	82.67±1.36[a]	79.63±1.20[b]	77.27±0.91[b]	78.60±0.87[b]
	2	83.00±1.83[a]	83.18±1.42[a]	84.57±0.80[a]	82.31±2.43[a]	83.75±1.05[a]
	4	84.79±1.85[a]	84.42±0.86[a]	83.42±1.95[a]	84.95±0.36[a]	83.28±0.81[a]
a	0	-3.25±0.37[a]	-2.96±0.67[a]	-0.58±0.37[a]	1.02±1.32[a]	1.53±1.25[a]
	2	-3.61±0.14[a]	-3.14±0.23[a]	-2.22±0.38[b]	-1.62±0.85[b]	-1.26±0.13[b]
	4	-3.08±0.52[a]	-2.99±0.39[a]	-1.67±0.43[b]	-1.90±0.44[b]	-2.48±1.40[b]
b	0	24.49±1.71[a]	26.09±2.72[a]	31.73±1.63[a]	29.96±4.69[a]	31.56±3.24[a]
	2	25.45±2.94[a]	26.67±1.97[a]	26.51±2.75[b]	26.83±1.67[a]	26.36±1.29[b]
	4	25.08±1.97[a]	25.29±1.29[a]	27.45±1.07[ab]	25.42±1.56[a]	25.65±2.23[b]

[1)]L, degree of whiteness (0 black-100 White); a, degree of redness (-80 greenness~100 redness); b, degree of yellowness (-80 blue~70 yellowness).
[2)a-b]All means in the same column followed by different letters are significantly different ($p<0.05$) as determined by Duncan's multiple range test.

Table 2. Changes in Hunter color values of ClO_2-treated fresh ginseng during storage at 4°C

Color parameter	ClO_2 treatment (ppm)	Storage period (day)				
		0	1	4	6	8
L	0	83.75±0.45[b]	82.16±0.69[b]	78.56±0.78[c]	78.35±1.47[b]	72.75±1.38[c]
	50	85.38±0.16[a]	85.62±0.80[a]	83.27±0.31[b]	80.74±0.94[a]	78.72±0.86[b]
	100	86.24±1.35[a]	86.15±1.38[a]	85.72±0.50[a]	82.7±0.40[a]	82.52±0.28[a]
a	0	-4.69±0.43[a]	-3.43±0.38[a]	0.18±0.99[a]	-0.60±1.60[a]	-0.71±1.50[a]
	50	-4.53±0.40[a]	-3.42±0.27[a]	-3.56±0.20[b]	-1.73±0.98[ab]	-2.21±0.33[b]
	100	-5.08±0.08[a]	-3.47±0.30[a]	-2.72±0.19[b]	-3.25±0.16[b]	-3.61±0.36[b]
b	0	28.52±1.71[a]	28.08±0.87[a]	38.23±0.51[a]	36.24±5.20[a]	40.00±2.30[a]
	50	27.24±1.00[a]	28.43±1.14[a]	28.92±2.64[b]	25.97±0.93[b]	32.30±1.16[b]
	100	26.09±0.55[b]	24.90±1.37[b]	26.79±1.49[b]	27.59±0.20[b]	28.1±0.52[b]

[a-b]All means in the same column followed by different letters are significantly different ($p<0.05$) as determined by Duncan's multiple range test.

Table 3. Sensory evaluation of electron beam-irradiated fresh ginseng during storage at 4°C

Organoleptic parameter	Irradiation dose (kGy)	Storage period (day)				
		0	2	4	6	8
Freshness	0	5.00±0.00[a]	5.00±0.00[a]	4.13±0.35[b]	3.38±0.52[b]	2.75±0.46[b]
	2	5.00±0.00[a]	5.00±0.00[a]	4.88±0.35[a]	3.88±0.35[ab]	3.38±0.74[ab]
	4	5.00±0.00[a]	5.00±0.00[a]	4.88±0.35[a]	4.13±0.64[a]	3.50±0.76[a]
Texture	0	5.00±0.00[a]	5.00±0.00[a]	4.38±0.52[b]	3.63±0.52[b]	3.13±0.64[b]
	2	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[ab]	4.38±0.52[a]	3.63±0.52[ab]
	4	5.00±0.00[a]	5.00±0.00[a]	5.00±0.00[a]	4.5±0.53[a]	3.75±0.46[a]
Decay	0	5.00±0.00[a]	5.00±0.00[a]	3.88±0.64[a]	3.25±0.71[b]	2.38±0.74[b]
	2	5.00±0.00[a]	5.00±0.00[a]	4.38±0.52[a]	4.00±0.76[ab]	3.38±0.74[a]
	4	5.00±0.00[a]	5.00±0.00[a]	4.50±0.53[a]	4.13±0.83[a]	3.13±0.83[ab]
Odor	0	5.00±0.00[a]	5.00±0.00[a]	3.75±0.46[b]	3.38±0.52[b]	3.00±0.76[a]
	2	5.00±0.00[a]	5.00±0.00[a]	4.12±0.64[ab]	3.75±0.46[ab]	3.50±0.53[a]
	4	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[a]	4.13±0.64[a]	3.75±0.89[a]
Overall	0	5.00±0.00[a]	5.00±0.00[a]	3.88±064[b]	3.25±0.71[b]	2.50±0.76[b]
	2	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[a]	3.88±0.35[a]	3.50±0.76[a]
	4	5.00±0.00[a]	5.00±0.00[a]	4.75±0.46[a]	4.13±0.35[a]	3.50±0.76[a]

[a-b]All means in the same column followed by different letters are significantly different ($p<0.05$) as determined by Duncan's multiple range test.

Table 4. Sensory evaluation of ClO_2-treated fresh ginseng during storage at 4°C

Organoleptic parameter	ClO_2 treatment (ppm)	Storage period (day)				
		0	1	4	6	8
Freshness	0	5.00±0.00[a]	5.00±0.00[a]	3.75±0.46[b]	3.75±0.46[b]	2.88±0.64[b]
	50	5.00±0.00[a]	5.00±0.00[a]	4.75±0.46[a]	4.25±0.46[ab]	3.75±0.46[a]
	100	5.00±0.00[a]	5.00±0.00[a]	4.88±0.35[a]	4.63±0.52[a]	4.25±0.46[a]
Texture	0	5.00±0.00[a]	5.00±0.00[a]	3.88±0.64[b]	3.88±0.64[b]	3.38±0.52[b]
	50	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[a]	4.25±0.89[ab]	4.00±0.53[a]
	100	5.00±0.00[a]	5.00±0.00[a]	4.88±0.35[a]	4.75±0.46[a]	4.38±0.52[a]
Decay	0	5.00±0.00[a]	5.00±0.00[a]	3.75±0.71[b]	3.50±0.53[b]	2.88±0.64[b]
	50	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[a]	4.25±0.46[a]	4.13±0.64[a]
	100	5.00±0.00[a]	5.00±0.00[a]	5.00±0.00[a]	4.75±0.46[a]	4.38±0.74[a]
Odor	0	5.00±0.00[a]	5.00±0.00[a]	3.88±0.64[b]	3.63±0.74[b]	3.50±0.53[a]
	50	5.00±0.00[a]	5.00±0.00[a]	4.75±0.46[a]	4.13±0.64[ab]	4.13±0.64[a]
	100	5.00±0.00[a]	5.00±0.00[a]	4.75±0.46[a]	4.50±0.54[a]	4.25±0.89[a]
Overall	0	5.00±0.00[a]	5.00±0.00[a]	3.88±064[b]	3.38±0.92[b]	3.00±0.38[b]
	50	5.00±0.00[a]	5.00±0.00[a]	4.63±0.52[a]	4.00±0.53[ab]	3.88±0.64[a]
	100	5.00±0.00[a]	5.00±0.00[a]	4.88±0.35[a]	4.63±0.52[a]	4.38±0.52[a]

[a-b]All means in the same column followed by different letters are significantly different ($p<0.05$) as determined by Duncan's multiple range test.

Hunter L value of the control decreased more than those of the samples irradiated at 2 and 4 kGy or treated with 50 and 100 ppm of aqueous ClO_2. In addition, Hunter a and b values of the control showed higher increases than those of the treated samples during storage, indicating that color change of the control was greater than the samples treated with electron beam or aqueous ClO_2. These results indicate that electron beam irradiation or aqueous ClO_2 treatment improves the color of the ginseng by preventing the red-colored phenomenon of the fresh ginseng. These results are comparable with those of other studies [Tsai *et al.*, 2001; Egea *et al.*, 2007].

Sensory evaluation of the inoculated fresh ginseng during storage is shown in Tables 3 and 4. Sensory qualities such as freshness, texture, decay, and odor were evaluated among treated samples during storage. Electron beam-irradiated or ClO_2-treated fresh ginseng had better sensory scores than the control.

In summary, the present study clearly indicated that electron beam irradiation or aqueous ClO_2 treatment significantly decreased the populations of *A. tumefaciens* in the fresh ginseng during storage, and was effective in maintaining the quality of the fresh ginseng. Therefore, electron beam irradiation or aqueous ClO_2 treatment can extend the shelf life and improve the microbial safety of the fresh ginseng during storage.

References

Bae JH and Lee DS (1999) Acute toxicity of chlorine dioxide to cultured-flounder (*Paralichthlys olivaceus*) and its bactericidal efficacy. *Korean J Lab Anim Sci* **15**, 87-91.

Black JL and Jaczynski J (2006) Temperature effect on inactivation kinetics of *Escherichia coli* O157:H7 by electron beam in ground beef, chicken breast meat, and trout fillets. *J Food Sci* **71**, 221-227.

Egea MI, Martinez-Madríd MC, Sánchez-Bel P, Murcia MA, and Romojaro F (2007) The influence of electron-beam ionization on ethylene metabolism and quality parameters in apricot (*Prunus armeniaca* L., cv Bulida). *Lebensmitt-wiss Technol* **40**, 1027-1035.

Ha DC, Lee JW, Do JH, Park CK, and Ryu GH (2004) Drying rate and physicochemical characteristics of dried ginseng root at different temperature. *J Korean Soc Food Sci Nutr* **33**, 741-746.

Hu W, Tanaka SI, Uchino T, and Nei D (2004) Storage life extension of ginseng using active modified atmosphere packaging by nitrogen generator. *J Faculty Agric Kyushu Univ* **49**, 401-408.

Jeon BS and Lee CY (1999) Shelf-life extension of American fresh ginseng by controlled atmosphere storage and modified atmosphere packaging. *J Food Sci* **64**, 328-331.

Jia YH, Li LP, Hou QM, and Pan Shen Q (2002) An *Agrobacterium* gene involved in tumorigenesis encodes an outer membrane protein exposed on the bacterial cell surface. *Gene* **284**, 113-124.

Jin Y, Shin H, and Song KB (2007) Electron beam irradiation improves shelf lives of Korean ginseng (*Panax ginseng C.A. Meyer*) and red ginseng. *J Food Sci* **72**, 217-222.

Kim JM, Maurice R, Marshall MR, Du WX, Steven Otwell, and Wei CI (1999) Determination of chlorate and chlorite and mutagenicity of seafood treated with aqueous chlorine dioxide. *J Agric Food Chem* **47**, 3586-3591.

Ku KJ, Ma YH, Shin HY, Lee SH, Park JH, Kim LH, and Song KB (2006) Effects of chlorine dioxide treatment on quality and microbial change of *Agaricus bisporus* sing during storage. *J Korean Soc Food Sci Nutr* **35**, 955-959.

Kwon JH, Byun MW, Kim KS, and Kang IJ (2000) Comparative effects of gamma irradiation and phosphine fumigation on the quality of white ginseng. *Rad Phys Chem* **57**, 309-313.

Lee SY, Gray PM, Dougherty RH, and Kang DH (2004) The use of chlorine dioxide to control *Alicyclobacillus acidoterrestris* spores in aqueous suspension and on apples. *Food Microbiol* **92**, 121-127.

Miller WR, Mcdonald RE, Mccollum TG, and Smittle BJ (1994) Quality of 'climax' blueberries after low dosage electron beam irradiation. *J Food Quality* **17**, 71-79

Owusu-Yaw J, Toth JP, Wheeler WB, and Wei CI (1990) Mutagenicity and identification of the reaction products of aqueous chlorine dioxide with L-tryptophan. *J Food Sci* **55**, 1714-1719.

Park HW, Lim TK, Choi CH, and Choi JE (2006) Factors and cause of rusty-ginseng occurrence. *Korean J Crop Sci* **51**, 396-400.

Razem D and Katusin-Razem B (2002) Dose requirements for microbial decontamination of botanical materials by irradiation. *Rad Phys Chem* **63**, 697-701.

Soriani RR, Satomi LC, and Pinto TJA (2005) Effects of ionizing radiation in ginkgo and guarana. *Rad Phys Chem* **73**, 239-242.

Tsai L-S, Huxsoll CC, and Robertson G (2001) Prevention of potato spoilage during storage by chlorine dioxide. *J Food Sci* **66**, 472-477.

Youm HJ, Ko JK, Kim MR, and Song KB (2004) Inhibitory effect of aqueous chlorine dioxide on survival of *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes* in pure cell culture. *Korean J Food Sci Technol* **36**, 514-517.

Wu VCH and Kim B (2007) Effect of a simple chlorine dioxide method for controlling five food borne pathogens, yeasts and molds on blueberries. *Food Microbiol* **24**, 794-800.