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ORIGINAL ARTICLE

Effects of Electron Beam and Ultraviolet-C Irradiation on Quality and Microbial Populations of Leafy Vegetables during Storage

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Abstract Effects of ultraviolet-C (UV-C) and electron beam irradiation on the quality and microbial populations of leafy vegetables were compared as a microbial decontamination method. Tatsoi and red chard leaves were treated with UV-C at a dose of 5 kJ/m^2 or by electron beam irradiation at doses of 0.5, 1, and 3 kGy. After UV-C or electron beam irradiation treatment, the samples were stored at 4 ± 1°C for 11 days. Populations of total aerobic bacteria in leafy vegetables decreased by 0.8–1.1 log CFU/g after treatment with UV-C irradiation, and those of yeast and molds decreased by 1.0–1.8 log CFU/g. On the contrary, electron beam irradiation at 0.5 or 1 kGy reduced the microbial populations by 2.0–2.5 log CFU/g. Electron beam irradiation at 3 kGy eliminated the microorganisms in the samples. These results suggest that electron beam irradiation at low dose below 3 kGy can be more effective than UV-C treatment for the inactivation of microorganisms in Tatsoi and red chard leaves.

Keywords irradiation · microorganisms · quality · vegetables

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Introduction

Consumption of minimally processed vegetables has increased due to changes in dietary habits and increasing interest on health. However, minimally processed vegetables are prone to contamination by microorganisms during harvest and processing due to the absence of thermal treatment (Chun et al., 2013; Han et al., 2000; Youm et al., 2005). Therefore, various non-thermal treatments, including irradiation treatments (Nthenge et al., 2007; Shin et al., 2012), organic acid (Akbas and lmez, 2007), ozone (Selma et al., 2007), pulsed-UV light (Bradley et al., 2012), chlorine (Beuchat et al., 2004), and chlorine dioxide (Lee et al., 2012) have been used to achieve microbial decontamination.

UV-C irradiation has been studied as a surface disinfectant for improving the microbiological safety of fruits and vegetables (Allende and Artes, 2003; Chun et al., 2010; Tomas-Callejas et al., 2012). In particular, a UV-C wavelength of 253.7 nm causes cross-linking between neighboring pyrimidine bases in DNA strands, resulting in the blockage of DNA transcription and replication and eventual cell death (Allende et al., 2006; Gabriel, 2012).

The use of ionizing radiation on foods has been accepted and is now legally recognized in many countries as a safe and effective method for improving food safety (Neal et al., 2010). Electron beam irradiation is used to inactivate food-borne microorganisms in foods and to guarantee the hygienic quality of foods (Grasso et al., 2011; Sarrias et al., 2003). Electron beam irradiation has a short processing time, does not produce radioactive waste (Black and Jaczynski, 2006), and destroys major food pathogenic bacteria (Rodriguez et al., 2006). Thus, electron beam irradiation can be used as a preservation method for fresh fruits and vegetables to achieve microbial decontamination.

Leafy vegetables such as Tatsoi and red chard are popularly consumed in the form of ready-to-eat salads due to their abundant

functional compounds, such as beta-carotene. However, there are always hazards and quality changes during storage caused by microbial contamination. Therefore, the objectives of the present study were to compare the effects of UV-C and electron beam irradiation on the inactivation of pre-existing microorganisms and the quality of Tatsoi and red chard leaves during storage as well as determine a suitable means of microbial decontamination for minimally processed vegetables.

Materials and Methods

Materials. Tatsoi (*Brassica rapa* var. *rosularis*) and red chard (*Beta vulgaris* var. *cycla*) as leafy vegetables were purchased from a local market in Daejeon, Korea and used intact for the experiment.

UV-C irradiation. UV-C irradiation was performed using unfiltered germicide emitting lamps (Sylvania, G15T8, Phillips, Netherlands), which were placed inside a custom-made metal cabinet (80 × 55 × 47 cm) as described in previous studies (Chun et al., 2010; Kim et al., 2010b). Tatsoi and red chard samples were placed on a stainless-steel tray without overlapping the samples and irradiated with the germicide-emitting lamps on both their upper and lower surfaces at a distance of 18 cm. The UV-C cabinet was designed according to the description given by Bolton and Linden (2003), and the UV lamps were allowed to warm up for 30 min before UV-C irradiation to ensure reproducible results. UV-C radiation intensity at 254 nm was measured using a UV radiometer (UV-340, Lutron Electronic Co., Ltd., Taiwan). The radiation dose was 5 kJ/m^2 for a 10.3 min exposure time, and the UV-C irradiation treatments were performed in a dark room to minimize photoreactivation of the microorganisms. After irradiation, the samples were individually packaged using low density polyethylene (LDPE) bags (100 mm × 170 mm, thickness, 2 mm) and stored at 4 ± 1°C for 11 days.

Electron beam irradiation. Electron beam irradiation was performed using an electron-beam accelerator (Model ELV-4, 2.5 MeV, Eb-Tech, Korea). The samples were individually packed in 100 mm × 170 mm LDPE bags (thickness, 2 mm) and were exposed to three doses of radiation: 0.5, 1, and 3 kGy at 2.5 MeV (beam current, 2.5 mA; beam dimension, 600 mm × 600 mm; conveyer velocity, 25 m/min). The dose characteristics of the accelerator were determined using cellulose triacetate dosimeter. After irradiation, the samples were stored at 4 ± 1°C for 11 days.

Water washing. For comparison, instead of UV-C or electron beam irradiation treatment, Totsoi and red chard samples were dipped in water solution for 5 min and then air dried in the laminar-flow hood for 1 h. The samples without any treatment were used as the control.

Microbiological analysis. Following treatment, the samples (20 g) were placed in 180 mL of peptone water (0.1% sterile peptone, w/v) in sterile stomacher bags. The samples were homogenized using a Stomacher (MIX 2, AES Laboratoire, France) for 3 min, filtered through a sterile cheese cloth, and diluted with peptone water (0.1% sterile peptone, w/v) to determine the microbial count. Serial dilutions were performed in triplicate on selective agar plates. Total bacteria counts were determined by plating appropriately diluted samples onto agar plates (PCA, Difco Co, USA). The samples were evenly spread on the surfaces of the plates with a sterile glass rod. Yeast and mold were plated on potato dextrose agar (PDA, Difco Co.). The experiments were repeated three times. PCA and PDA plates were incubated at 37°C for 48 h and at 25°C for 72 h, respectively. Each microbial count was the mean of three determinations. The microbial counts were expressed as log CFU/g.

Color measurement. Colors of the samples were analyzed using a colorimeter (CR-400 Minolta Chroma Meter, Konica Minolta Sensing Inc., Japan). The samples were placed on a white standard plate, and the Hunter's color values (L*, a*, b*) were measured. Hunter's L*, a*, and b* values for the standard plate were 96.37, 0.17, and 1.98, respectively. For each sample, five measurements were taken at different locations.

Sensory evaluation. The appearance, odor, and overall acceptability of the samples were analyzed by eight trained panelists. The sensory qualities of the samples were evaluated using a nine-point scoring method and scored on the following scale: 9–8, very good; 7–6, good; 5-4, fair; 3–2, poor; and 1, very poor.

Statistical analysis. Analysis of variance and Duncan's multiple range tests with significance at $p < 0.05$ were performed using the SAS program (SAS Institute, Inc., USA). All samples were expressed as the means ± standard deviation.

Results and Discussion

Microbiological analysis. The effects of electron beam or UV-C irradiation on the microbial growth in Tatsoi and red chard leaves during storage were examined (Fig. 1–4). The initial populations of total aerobic bacteria in fresh Tatsoi and red chard leaves were 5.56 and 5.82 log CFU/g, respectively (Figs. 1 and 2). After washing with water, the populations of total aerobic bacteria in Tatsoi and red chard leaves marginally decreased to 5.20 log CFU/g, a reduction of 0.36 and 0.62 log CFU/g, respectively. Similarly, Kim et al. (2011) reported that water treatment reduced the populations of microorganisms in red chicory and pak choi by 0.21 and 0.44 log CFU/g, respectively. UV-C treatment at 5 kJ/m^2 reduced the total aerobic bacteria populations in Tatsoi and red chard leaves to 4.85 and 4.63 log CFU/g, resulting in a 0.79 and 1.09 log CFU/g reduction, respectively, compared to the control. Similar to our results, Guan et al. (2012) reported a reduction of 0.67–1.13 log CFU/g by UV-C treatment at 0.45–3.15 kJ/m^2 for button mushrooms inoculated with *E. coli* O157:H7. Along with these reports, our results suggest that washing with water or UV-C treatment is not sufficient for the microbial decontamination of Tatsoi and red chard leaves.

On the contrary, after treatment with electron beam irradiation

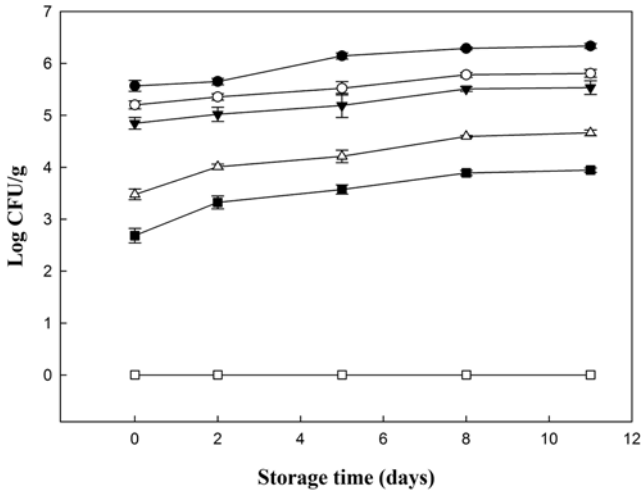

Fig. 1 Effects of non-thermal treatments on the growth of total aerobic bacteria in Tatsoi during storage. ●: Control; ○: Water washing; ▼: UV-C; ▽: E-beam 0.5 kGy; ■: E-beam 1 kGy; □: E-beam 3 kGy. Bars represent standard errors (n=3).

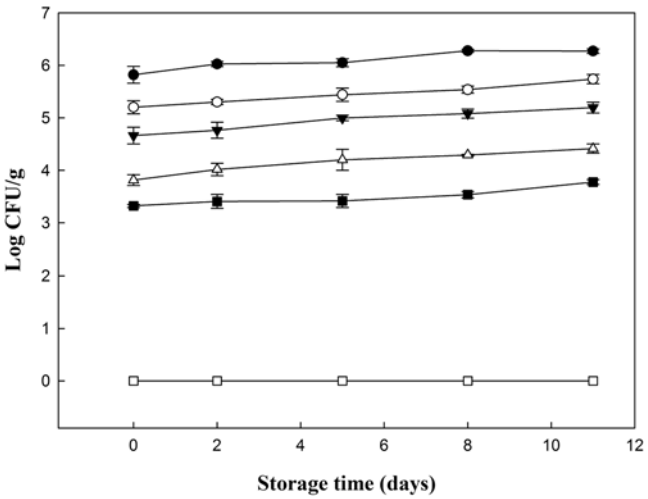

Fig. 2 Effects of non-thermal treatments on the growth of total aerobic bacteria in red chard during storage. ●: Control; ○: Water washing; ▼: UV-C; ▽: E-beam 0.5 kGy; ■: E-beam 1 kGy; □: E-beam 3 kGy. Bars represent standard errors (n=3).

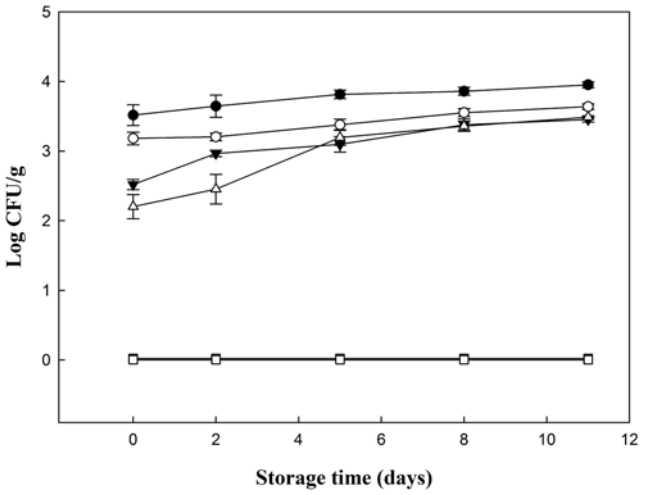

Fig. 3 Effects of non-thermal treatments on the growth of yeast and molds in Tatsoi during storage. ●: Control; ○: Water washing; ▼: UV-C; ▽: E-beam 0.5 kGy; ■: E-beam 1 kGy; □: E-beam 3 kGy. Bars represent standard errors (n=3).

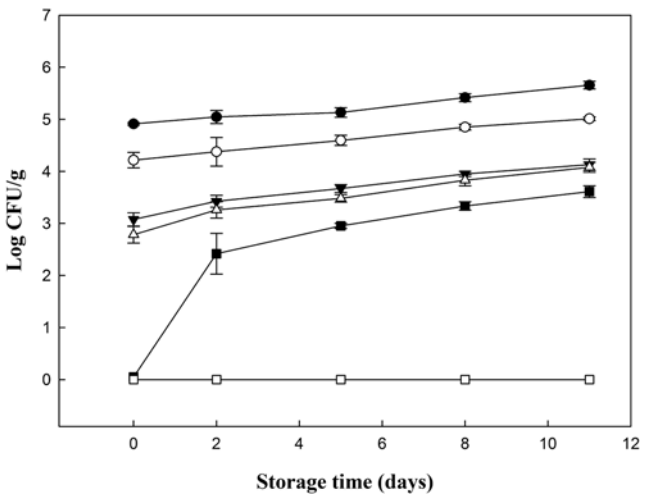

Fig. 4 Effects of non-thermal treatments on the growth of yeast and molds in red chard during storage. ●: Control; ○: Water washing; ▼: UV-C; ▽: E-beam 0.5 kGy; ■: E-beam 1 kGy; □: E-beam 3 kGy. Bars represent standard errors (n=3).

at 0.5 kGy, the populations of total aerobic bacteria in the Tatsoi and red chard leaves were reduced to 3.48 and 3.81 log CFU/g, respectively, resulting in a reduction of 2.08 and 2.01 log CFU/g, respectively, compared to the control (Figs. 1 and 2). In addition, at 1 kGy irradiation, total populations of aerobic bacteria in Tatsoi and red chard leaves decreased to 2.68 and 3.32 log CFU/g, respectively. Similar to our results, irradiation of cooked ham at 1 kGy resulted in a 1.5–2.5 log CFU/g decrease in the microorganism population (Juan et al., 2011). In contrast to radiation doses of 0.5 and 1 kGy, aerobic bacteria in Tatsoi and red chard leaves could not be detected after electron beam irradiation at 3 kGy, which represents the most effective means of microbial decontamination. Bhat et al. (2010) also reported that yeast and molds in lotus seeds were eliminated by electron beam irradiation at 7.5 kGy, although this dose is higher than that used in the present investigation. Grasso et al. (2011) also reported that electron beam irradiation increased the safety of fresh-cut cabbage by reducing or eliminating microorganisms.

The degree of total aerobic bacteria inactivation in the samples by UV-C or electron beam irradiation was maintained during storage. After 5 days of storage, the populations of total aerobic bacteria in the control Tatsoi samples increased to 6.14 log CFU/

Table 1 Change in Hunter color values of non-thermal treated Tatsoi during storage at 4°C

Color parameter	Treatment[a]	Storage time (day)				
		0	2	5	8	11
L*	Control	40.85±2.40Aa[b]	39.86±1.22Aa	40.00±0.66Aa	41.21±1.81Aa	41.50±1.01Aa
	Water	39.55±1.50Aa	40.92±0.80Aa	40.81±1.36Aa	41.20±1.82Aa	41.27±0.98ABa
	UV-C	40.73±0.77Aa	40.08±1.89Aa	39.67±1.02Aa	41.25±1.17Aa	39.84±1.69Ba
	E-beam 0.5 kGy	39.96±0.42Aab	40.78±1.30Aab	39.62±0.73Ab	41.29±1.41Aa	41.16±1.00ABa
	1 kGy	40.79±1.22Aa	41.38±1.93Aa	40.48±2.04Aa	40.94±0.76Aa	40.75±0.51ABa
	3 kGy	40.24±1.95Aa	40.10±1.08Aa	40.90±1.86Aa	41.22±0.60Aa	39.87±0.63Ba
a*	Control	-13.54±1.22Aa	-12.53±1.06Aa	-13.33±0.48ABa	-12.94±1.15Aa	-13.15±0.73Aa
	Water	-13.21±0.41Aab	-12.38±0.66Aa	-12.68±0.46Aab	-12.74±1.13Aab	-13.39±0.33Ab
	UV-C	-13.08±0.41Aab	-12.72±0.45Aa	-13.63±0.28Bb	-13.31±0.37Aab	-13.08±0.60Aab
	E-beam 0.5 kGy	-13.16±0.71Aa	-12.71±1.22Aa	-13.00±0.60ABa	-13.55±0.27Aa	-13.58±0.27Aa
	1 kGy	-13.51±0.10Aa	-12.62±1.32Aa	-13.00±0.49ABa	-13.35±0.32Aa	-13.15±0.44Aa
	3 kGy	-13.75±0.18Ab	-13.13±0.63Aab	-13.09±0.73ABab	-13.72±0.15Ab	-12.97±0.53Aa
b*	Control	21.05±2.82Aa	20.14±1.36Aa	21.40±0.92Aa	21.86±2.11Aa	20.00±1.12Aa
	Water	20.61±0.96Aa	20.38±1.93Aa	20.10±0.41Aa	21.63±2.54Aa	20.86±1.49Aa
	UV-C	20.03±1.25Aa	20.52±0.85Aa	21.15±0.86Aa	21.39±1.08Aa	21.50±1.62Aa
	E-beam 0.5 kGy	20.35±0.35Aa	20.79±2.24Aa	20.55±1.43Aa	20.30±1.86Aa	19.75±0.57Aa
	1 kGy	21.04±1.65Aa	20.37±1.50Aa	20.71±1.84Aa	20.93±1.69Aa	19.56±1.14Aa
	3 kGy	21.19±0.70Aa	21.62±1.78Aa	20.53±1.87Aa	20.51±1.98Aa	21.27±2.04Aa

[a]Control: no treatment, Water: water washing, UV-C: 5 kJ/m^2 treatment, E-beam: electron beam irradiation.
[b]Any means in the same row or column followed by the same letters are not significantly (p <0.05) different.

g, while the samples treated with UV-C irradiation increased to 5.19 log CFU/g. For the samples treated by electron beam irradiation at 0.5 and 1 kGy, the populations of total aerobic bacteria in Tatsoi leaves were 4.21 and 3.57 log CFU/g, respectively, resulting in a significant difference compared to the non-treated samples. A similar pattern was observed for the red chard leaves during storage. After 5 days of storage, the total population of aerobic bacteria in the non-treated red chard leaves increased to 6.05 log CFU/g, whereas UV-C treatment and electron beam irradiation at 0.5 and 1 kGy resulted in decreased total aerobic bacteria populations of 4.99, 4.20, and 3.42 log CFU/g, respectively. In particular, electron beam irradiation at 3 kGy resulted in the elimination of total aerobic bacteria after 11 days of storage. These results suggest that electron beam irradiation at 3 kGy can prevent bacterial growth during the storage of Tatsoi and red chard leaves. The mechanism of microbial inactivation by electron beam irradiation had been reported to result from a homeostatic imbalance of cells and DNA damage within the microorganisms in the samples (Fielding et al., 1997; Ko et al., 2005).

Yeast and mold showed a similar pattern to aerobic bacteria during storage, and initial populations of yeast and molds in the fresh Tatsoi and red chard leaves were 3.52 and 4.91 log CFU/g, respectively (Figs. 3 and 4). After washing with water, the yeast and mold populations in Tatsoi and red chard leaves were 3.18 and 4.21 log CFU/g, and UV-C treatment reduced the yeast and mold populations in Tatsoi and red chard leaves to 2.52 and 3.08 log CFU/g, respectively. Electron beam irradiation at 0.5 kGy reduced the yeast and mold populations to 2.20 and 2.78 log CFU/g, resulting in a reduction of 1.32 and 2.13 log CFU/g, respectively.

After 11 days in storage, electron beam irradiation at 0.5 kGy reduced the yeast and mold populations in Tatsoi and red chard leaves to 3.49 and 4.08 log CFU/g, respectively (Figs. 3 and 4). In contrast to the populations of total aerobic bacteria, the initial yeast and mold populations were not detected after treatment by electron beam irradiation at 1 and 3 kGy, and these effects were maintained in the Tatsoi leaves during storage. However, in the case of red chard leaves irradiated at 1 kGy, the populations of yeast and mold increased to 3.61 log CFU/g after 11 days of storage. This phenomenon might be explained by the reactivation of injured yeasts and molds during storage. Similar results showing the photo-reactivation of *E. coli* after electron beam irradiation have been previously reported (Michael et al., 1981). In the present investigation, electron beam irradiation at 3 kGy eliminated the microbial growth in Tatsoi and red chard leaves during storage, suggesting that it is an effective microbial decontamination method for minimally processed vegetables. Therefore, based on the results of the present investigation regarding the effects of UV-C and electron beam irradiation on the inactivation of microorganisms in Tatsoi and red chard leaves during storage, electron beam irradiation is a more suitable treatment for microbial contamination than UV-C irradiation.

Color measurement and sensory evaluation. The colors of Tatsoi and red chard leaves were determined using a colorimeter (Tables 1 and 2). The L* value of the Tatsoi leaves indicated an initial value of approximately 40, and there were no significant differences among the treatments during storage. The a* and b*

Table 2 Change in Hunter color values of non-thermal treated red chard during storage at 4°C

Color parameter	Treatment	Storage time (day)				
		0	2	5	8	11
L*	Control	43.99±0.63Aa[a]	44.21±1.46Aa	44.23±0.75Aa	43.86±0.91Aa	43.88±0.79Aa
	Water	44.23±1.29Aa	43.95±0.57Aa	43.34±0.70Aa	44.90±2.68Aa	43.89±0.84Aa
	UV-C	44.47±0.71Aa	43.27±0.87Ab	43.12±0.36Ab	45.42±1.08Aa	43.92±1.45Aab
	E-beam 0.5 kGy	44.85±0.63Aa	44.42±0.67Aab	44.59±1.71Aa	43.10±1.08Ab	44.81±0.90Aa
	1 kGy	44.99±0.63Aa	43.76±1.13Aa	43.81±1.76Aa	43.59±1.10Aa	43.93±0.95Aa
	3 kGy	44.57±1.25Aa	44.50±1.47Aa	43.16±0.72Aa	44.93±1.49Aa	44.11±1.63Aa
a*	Control	-15.59±1.23Aa	-15.14±0.49Aa	-15.94±0.87Aa	-15.60±0.52Ba	-15.46±1.00Aa
	Water	-14.88±0.95Aa	-15.91±0.49Aa	-15.68±0.48Aa	-15.84±1.08Ba	-15.42±1.24Aa
	UV-C	-14.86±0.68Aa	-15.08±0.71Aa	-14.95±1.35Aa	-14.28±1.38Aa	-15.11±0.83Aa
	E-beam 0.5 kGy	-14.58±1.19Aa	-15.31±0.48Aa	-15.48±1.48Aa	-15.73±0.70Ba	-15.82±0.36Aa
	1 kGy	-14.94±1.09Aa	-15.84±1.02Aa	-15.85±0.79Aa	-15.77±1.11Ba	-15.60±0.91Aa
	3 kGy	-15.06±0.52Aab	-15.76±0.65Ab	-14.72±0.76Aab	-14.16±0.74Aa	-14.38±1.18Aab
b*	Control	23.79±0.62Bc	23.37±0.44Bc	24.07±0.75Bbc	25.53±1.57Aa	25.22±0.79Aab
	Water	24.95±0.44Aa	24.93±1.35ABa	25.53±0.51Aa	25.57±1.09Aa	25.06±1.29Aa
	UV-C	23.84±0.54Ba	23.48±0.90Ba	24.07±0.17Ba	24.92±1.91Aa	24.33±1.63Aa
	E-beam 0.5 kGy	24.96±0.91Aa	23.62±1.37ABb	25.50±1.38Aa	25.53±0.23Aa	25.21±0.45Aa
	1 kGy	24.58±0.32ABa	24.69±1.26ABa	24.55±1.44ABa	24.38±1.09Aa	25.38±0.96Aa
	3 kGy	24.01±0.79Ba	25.17±1.13Aa	24.14±0.56Ba	24.36±0.98Aa	24.68±0.81Aa

[a]Any means in the same row or column followed by the same letters are not significantly (p <0.05) different.

Table 3 Sensory evaluation of non-thermal treated Tatsoi during storage at 4°C

Sensory attributes	Treatment	Storage time (day)				
		0	2	5	8	11
Appearance	Control	9.00±0.00Aa[a]	8.88±0.35Aa	8.25±0.71Aab	7.75±0.89Ab	6.75±1.16Ac
	Water	9.00±0.00Aa	8.75±0.46Aa	8.13±0.83Aab	7.63±1.06Ab	6.63±1.19Ac
	UV-C	8.75±0.46Aa	8.13±0.64Aab	7.75±0.46Abc	7.13±0.64Ac	5.88±1.55Ad
	E-beam 0.5 kGy	8.88±0.35Aa	8.88±0.35Aa	8.13±0.35Ab	7.38±0.52Ac	6.63±0.92Ad
	1 kGy	8.88±0.35Aa	8.75±0.46Aa	8.00±0.53Ab	7.38±0.52Ac	6.50±0.93Ad
	3 kGy	8.88±0.35Aa	8.50±0.53Aa	7.63±0.92Ab	7.00±0.53Ab	6.00±1.07Ac
Odor	Control	9.00±0.00Aa	8.88±0.35Aa	7.88±0.83Ab	7.38±0.92Abc	6.63±1.06Ac
	Water	9.00±0.00Aa	8.75±0.46Aa	7.88±0.83Ab	7.38±0.92Ab	6.50±1.07Ac
	UV-C	8.88±0.35Aa	8.38±0.74Aab	7.63±0.74Abc	7.13±0.83Ac	6.25±1.16Ad
	E-beam 0.5 kGy	8.88±0.35Aa	8.88±0.35Aa	8.00±0.53Ab	7.38±0.52Ac	6.50±0.93Ad
	1 kGy	8.88±0.35Aa	8.75±0.46Aa	7.88±0.64Ab	7.38±0.52Ab	6.38±0.92Ac
	3 kGy	8.88±0.35Aa	8.63±0.52Aa	7.88±0.64Ab	7.25±0.46Ac	6.25±0.89Ad
Overall acceptability	Control	9.00±0.00Aa	8.88±0.35Aa	8.25±0.71Aab	7.63±1.07Ab	6.75±1.16Ac
	Water	9.00±0.00Aa	8.75±0.46Aa	8.13±0.83Aab	7.63±1.06Ab	6.63±1.19Ac
	UV-C	8.75±0.46Aa	8.25±0.71Aab	7.50±0.53Abc	7.13±0.64Ac	6.00±1.60Ad
	E-beam 0.5 kGy	8.88±0.35Aa	8.88±0.35Aa	8.13±0.35Ab	7.38±0.52Ac	6.63±0.92Ad
	1 kGy	8.88±0.35Aa	8.75±0.46Aa	8.00±0.53Ab	7.38±0.52Ac	6.50±0.93Ad
	3 kGy	8.88±0.35Aa	8.50±0.53Aa	7.63±0.92Ab	7.00±0.53Ab	6.00±1.07Ac

[a]Any means in the same row or column followed by the same letters are not significantly (p <0.05) different.

values of Tatsoi leaves were around −13 and 20, respectively, also with no significant changes among the treatments during storage. For the red chard leaves samples, the L*, a*, and b* values were approximately 44, −14, and 24, respectively. The b* value of the control red chard leaves slightly increased during storage, whereas the b* values of the UV-C- and electron beam-irradiated samples did not increase during 11 days of storage. Overall, our results clearly show that UV-C and electron beam irradiation do not cause a change in color, which is in good agreement with the results of other studies (Jin et al., 2006; Kim et al., 2010a).

Table 4 Sensory evaluation of non-thermal treated red chard during storage at 4°C

Sensory attributes	Treatment	Storage time (day)				
		0	2	5	8	11
Appearance	Control	9.00±0.00Aa[a]	8.50±0.53Aab	8.13±0.64Ab	7.00±1.07Ac	6.13±1.13Ad
	Water	9.00±0.00Aa	8.88±0.35Aab	8.25±0.71Ab	7.00±0.76Ac	6.13±1.13Ad
	UV-C	9.00±0.00Aa	8.88±0.35Aa	8.25±0.71Aa	6.63±1.60Ab	5.75±1.67Ab
	E-beam 0.5 kGy	9.00±0.00Aa	8.88±0.35Aa	7.88±0.99Ab	6.88±1.25Ac	5.25±1.04Ad
	1 kGy	9.00±0.00Aa	8.88±0.35Aa	7.88±0.99Ab	6.50±1.31Ac	5.38±1.06Ad
	3 kGy	9.00±0.00Aa	8.88±0.35Aa	7.50±0.76Ab	6.50±0.76Ac	5.25±0.71Ad
Odor	Control	9.00±0.00Aa	8.63±0.52Aa	8.25±0.46Aa	7.00±1.07Ab	5.88±1.13Ac
	Water	9.00±0.00Aa	8.75±0.46Aa	8.25±0.71Aa	7.25±1.04Ab	5.88±1.13Ac
	UV-C	9.00±0.00Aa	8.75±0.46Aa	8.25±0.71Aa	6.75±1.83Ab	5.50±1.60Ac
	E-beam 0.5 kGy	9.00±0.00Aa	8.75±0.46Aa	8.00±1.07Aab	7.00±1.51Ab	5.25±1.16Ac
	1 kGy	9.00±0.00Aa	8.75±0.46Aa	8.00±1.07Aa	6.88±1.64Ab	5.38±1.19Ac
	3 kGy	9.00±0.00Aa	8.75±0.46Aab	8.00±0.93Ab	7.00±1.31Ac	5.38±0.74Ad
Overall acceptability	Control	9.00±0.00Aa	8.50±0.53Aa	8.25±0.71Aa	7.00±1.07Ab	6.00±1.20Ac
	Water	9.00±0.00Aa	8.75±0.46Aa	8.25±0.71Aa	7.00±0.76Ab	6.00±1.20Ac
	UV-C	9.00±0.00Aa	8.88±0.35Aa	8.38±0.74Aa	6.63±1.60Ab	5.63±1.69Ab
	E-beam 0.5 kGy	9.00±0.00Aa	8.88±0.35Aa	7.88±0.99Ab	6.75±1.28Ac	5.25±1.04Ad
	1 kGy	9.00±0.00Aa	8.75±0.46Aab	7.88±0.99Ab	6.63±1.30Ac	5.38±1.06Ad
	3 kGy	9.00±0.00Aa	8.75±0.71Aa	7.50±0.76Ab	6.63±0.74Ac	5.25±0.71Ad

[a]Any means in the same row or column followed by the same letters are not significantly (p <0.05) different.

The sensory evaluations of Tatsoi and red chard leaves during storage are shown in Tables 3 and 4. Sensory qualities such as appearance, odor, and overall acceptability during storage were examined following the treatments. All sensory quality values of Tatsoi and red chard leaves significantly decreased during storage for all treatments. These results are very similar to a previous report, where strawberry "Flamengo" samples were treated by UV-C irradiation and fumaric acid (Kim et al., 2010b). In addition, all sensory qualities in the Tatsoi and red chard leaves were similar among treatments during storage. Therefore, these results indicate that UV-C and electron beam irradiation did not affect the sensory qualities of Tatsoi and red chard leaves during storage.

In summary, electron beam irradiation was more effective in decreasing the number of pre-existing microorganisms in Tatsoi and red chard samples than UV-C treatment. In particular, electron beam irradiation at 3 kGy eliminated the aerobic bacteria as well as yeast and mold in Tatsoi and red chard leaves. These results suggest that electron beam irradiation at 3 kGy can be an effective microbial decontamination method for Tatsoi and red chard leaves before storage.

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