J Korean Soc Appl Biol Chem (2015) 58(1):149–156
DOI 10.1007/s13765-015-0022-1

Online ISSN 2234-344X
Print ISSN 1738-2203

ARTICLE

Effects of ultraviolet radiation on the physicochemical characteristics of Korean native cattle (Hanwoo) beef

Hyun-Jung Kim · Yong Jae Lee · Jong-Bang Eun

Received: 7 August 2014 / Accepted: 10 December 2014 / Published online: 29 January 2015

Abstract The effects of ultraviolet (UV) radiation on the physicochemical characteristics of Korean native cattle (Hanwoo) beef with regards to shelf life were investigated in this research. The Hanwoo beef was exposed to UV radiation (4.5 mW s/cm^2) for 0, 5, 10, 15, and 20 min. The results showed no differences in physicochemical parameters such as pH, drip loss, and shear force for all of the beef samples that were treated during storage. Lightness (L^* value) and yellowness (b^* value) did increase during storage. The redness (a^* value) of all of the Hanwoo beef tended to increase until day 6 of storage, but then decreased afterward. The non-radiated beef had higher L^*, a^*, and b^* values than UV-radiated Hanwoo beef. Furthermore, the UV-radiated beef showed significantly higher thiobarbituric acid values during storage as compared to those of non-radiated beef. No differences in the volatile basic nitrogen values in any of the beef samples were observed during storage. The sensory evaluation also showed no significant differences between the UV radiation treatments. The results verified that the physicochemical characteristics of beef were not significantly affected by UV radiation treatments.

H.-J. Kim · J.-B. Eun (✉)
Department of Food Science and Technology and Functional Food Research Center, Chonnam National University, Gwangju 500-757, South Korea
e-mail: jbeun@jnu.ac.kr

H.-J. Kim
e-mail: cleanhj@hanmail.net

Y. J. Lee
Food Protein R&D Center, Texas A&M University, College Station, TX 77843, USA
e-mail: lee9623@gmail.com

Keywords Ultraviolet (UV) radiation · Korean native cattle (Hanwoo) beef · Physicochemical characteristics · pH · Drip loss · Shear force · Sensory evaluation

Introduction

Meat consumption, especially beef, has increased significantly with the rapid economic development and rising per capita incomes in Korea in the last two decades (Lee and Cho 2012). Beef consumption per capita in Korea was changed from 1.2 to 10.7 kg, an increase of about 800 % from 1997 to 2011. With the expectations of continued economic growth of Korea, the meat market should significantly grow further (Jo et al. 2012). According to the references, Hanwoo beef contains highly marbled fat, thin muscle fibers, and minimum connective tissues (Kim et al. 1994; Cho et al. 2005; Jo et al. 2012) which are attractive elements for consumers; therefore, Hanwoo beef has better quality and is fresher than other imported beef (Kim and Lee 2000; Han and Lee 2010) although more expensive. Due to the increasing consumer demand, it is now important to study ways of prolong Hanwoo beef storage periods.

The ultraviolet (UV) radiation method is considered one of the best ways to increase shelf life and preserve beef quality. UV has a shorter wavelength region than visible light (400 nm) but longer than X-rays (100 nm), and it is well known that UV has sterilization and disinfecting effects. UV from 100 to 280 nm has typically been used for sterilization purposes. The UV disinfection method of food radiation does not affect food quality or bacterial resistance. It is a very simple and safe method without residual components (Ryeong 1996). UV radiation has been studied to improve the storage period of onions (Lu et al. 1987; Perez-Gregorio et al. 2011), sweet potatoes (Stevens et al. 1990; Chan et al. 2010), apples (Wilson et al. 1997), apple cider (Harrington and Claude 1968;

Assatarakul et al. 2012), whole fish (Huang and Toledo 1982; Sucre et al. 2012), shelled eggs (Kuo et al. 1997), and fresh-cut fruit (Manzocco et al. 2011). However, it has not been established as a practical and commercial food sterilization method because of the public perception that UV radiation is unsafe. Moreover, it is not very penetrating on muscle surface which must be directly exposed to the rays to kill the pathogenic microorganisms. Our previous study was verified that UV radiation can effectively inhibited the growth of pathogenic bacteria on the surface of meat and improved the meat's microbial safety. In this study, we investigated the physicochemical characteristics and conducted a sensory evaluation of UV-radiated Hanwoo beef to confirm and improve the safety of this type of storage without changing the quality of the beef.

Materials and methods

Materials

The cull female Hanwoo beef was obtained from Boseong-Gun, Chola-Nam-Do, South Korea in the form of a 4-year old weighing approximately 301 kg. About 1-cm-thick slices of beef muscle (*Longissimus dorsi* muscle at the 13th rib interface) were cut 5 h after slaughter for use in the experiment. The muscle slices were packaged in polyethylene bags using a vacuum system and stored at 2 °C in the chilling room until used. Sample (approximately 250 g) of the muscle was prepared and frozen in liquid nitrogen and stored at −70 °C until analysis for chemical–physical characteristics.

Methods

UV radiation

A UV lamp (germicidal lamp G10T8, Sankyo Denki Co., Ltd., Tokyo, Japan) was equipped with a wavelength of 254 nm and a 10 W output. Each bank contained 10 lamps and was mounted above and below the device. UV radiation intensity was measured using a UVX digital radiometer (UVP, Inc., Upland, CA, USA). UV radiation was applied at 4.5 mW/cm^2 for 0, 5, 10, 15, and 20 min. The beef radiated with UV was put on a polystyrene foam tray and packed with polyvinylchloride wrap, then stored at 4 ± 1 °C (BI-100 M, JEIO TECH, Seoul, Korea). The samples were investigated over a 9-day storage period.

Proximate composition analysis

Moisture, crude ash, crude protein, and crude fat were determined using an AOAC (2006) method. Approximately, 10 g of the sample was dried at 105 °C until constant weight and moisture content could be determined gravimetrically. The dried sample was thereafter combusted at 550 °C overnight to determine ash content. Crude protein was extracted and determined using the micro-Kjeldahl method, via an automatic nitrogen analyzer (UDK 130A, VELP Scientifica, Italy). The crude lipids content was determined by Soxhlet extraction method.

Physical and chemical analysis

pH A 10 g portion of beef was mixed with 20 ml distilled water and homogenized to measure the pH using a meter (VWR Scientific, model 8000; Choi et al. 1995). The pH was measured at 0, 2, 4, 6, 7, 8, and 9 days of storage at 4 °C after being treated with UV radiation at various times.

Drip loss Drip loss was calculated by finding the difference in levels before and after the storage period (Kim and Cheong 1999). Drip loss was calculated by the following equation:

$$\text{Drip loss } (\text{g}/100\ \text{g}) = \frac{W_\text{o} - W_\text{t}}{W_\text{o}} \times 100,$$

where W_o is the pre-weighted beef weight and W_t is the beef weight after storage.

Color Meat color was measured using a color difference meter (spectrophotometer, Minolta CM-3500d, Tokyo, Japan); the color of the meat was measured 10 times at the front and the rear sides of the beef and expressed with L^*, a^*, and b^* values (L lightness, a redness, and b yellowness). Zero calibration was set up with a CM-A124 box, and white calibration was set up with a CM-A120 box.

Shear force Shear force was considered to be the rate of force required to cut the beef (kg/cm^2) at a speed of 3 mm/s. It was measured by a Warner–Bratzler texture analyzer (TA-XT2, Stable Micro Systems, Hasemere, England) while producing a 2.5 × 5 × 1 cm beef slice.

Thiobarbituric acid (TBA) value TBA values were measured as described by Witte et al. (1970). Beef (20 g) was mixed using a mixer (Hanil FM 909T, Seoul, Korea) and 50 ml 20 % 2-trichloroacetic acid solution dissolved in a 2 M phosphate. The sample was homogenized (homogenizer, AM-3, Nihonseiki Kaisha Ltd., Tokyo, Japan) at a speed of 10,000 rpm for 2 min; then the filtering process was repeated using Whatman #1 and #5 filter paper, adjusted to a constant level of 100 ml using distilled water. The 5 ml filtered solution was mixed with 5 ml 5 mM 2-thiobarbituric acid followed by boiling for 35 min in a 100 °C water bath and cooling for 10 min in cold water.

Absorbance at 530 nm was measured by a spectrophotometer (UV-1201, Shimadzu).

Volatile basic nitrogen (VBN) The VBN value was measured as described by Yi and Sung (1984). The 10 g of beef was mixed with 30 ml distilled water. The sample was homogenized at a speed of 10,000 rpm for 2 min. Then, the sample was filtered with Whatman #1 and #5 filter paper and adjusted to 100 ml with distilled water. The 1 ml filtered solution was put in the outer space of a Conway unit. The 1 ml 0.01 N H_3BO_3 and 2–3 drops of Conway reagent (1:1 mixture with 6.6×10^{-2} % methyl red and 6.6×10^{-2} % bromocresol green) were put in the inner space of the Conway unit. After adding 1 ml of K_2CO_3 solution (to the upper layer, after dissolving 50 g K_2CO_3 in 100 ml of distilled water), the Conway unit was sealed immediately, using glycerin. The sealed Conway unit was shaken slowly and incubated at 37 °C for 2 h, then titrated with a 0.01 N H_2SO_4 solution. The VBN value was calculated by the following equation:

$$\text{VBN (mg/100 g)} = \frac{(B - A) \times f \times N \times D \times 14.007}{S} \times 100,$$

where (S) is the meat sample weight (g), (A) is the volume of the H_2SO_4 solution added to the blank (ml), (B) is the volume of H_2SO_4 solution added to the sample (ml), (N) is the normal concentration of the H_2SO_4 solution, (f) is the standard factor, (D) is the dilution factor, and 14.007 is the nitrogen content (mg) that was reacted with 1 ml of the 1 N H_2SO_4 solution.

Sensory changes during storage

Ten sensory test experts participated in this study. They observed, smelled, and felt five different beef samples exposed for 0, 5, 10, 15, and 20 min to UV radiation after 9 days of storage. Five parameters (odor, tenderness, color, succulence, and overall acceptability) were ranked from good (one point) to bad (seven points) (Choi and Yeo 1998).

Statistical analysis

The statistical analysis was performed using an SAS program (2003). Replicate samples were collected and triplicate analyses were conducted by analysis of variance using a general linear model procedure. The statistical significance of the differences among the different treatment means was accessed by Duncan's multiple range tests. Differences were considered significant for P-values lower than 0.05.

Results and discussion

Proximate composition analysis

The results of the proximate composition analysis (moisture, crude ash, crude protein, and crude fat) of the Hanwoo beef treated with 0, 10, and 20 min of UV radiation are shown in Table 1. The Hanwoo beef contained 71.64 % moisture, 0.96 % crude ash, 18.25 % crude protein, and 4.78 % crude fat. No significant compositional difference was observed between the UV radiation-treated and UV radiation-untreated beef ($P < 0.05$). Fat content was significantly low in this cull female beef (18.15 %) compared to 1++ quality grade Hanwoo steer *Longissimus* (21.48 %) (Cho et al. 2005). UV rays are not capable of penetrating solid foods such as meat, and can only affect the surface and inhibit the growth of pathogenic microorganisms while avoiding negative effects on meat quality (Gailunas 2003). Therefore, overall composition is unlikely to change with UV treatment.

Physicochemical changes during refrigeration

pH

The pH changes in the Hanwoo meat following UV radiation during storage at 4 °C for 9 days are shown in Fig. 1.

Table 1 Results of the proximate composition analysis of Hanwoo beef treated with UV radiation

Proximate compositions	UV radiation time (min)		
	0	10	20
Moisture	71.64 ± 2.44[a]	73.41 ± 1.58[ab]	71.43 ± 2.47[a]
Crude ash	0.96 ± 0.17[a]	0.91 ± 0.12[ab]	0.97 ± 0.25[a]
Crude protein	18.25 ± 1.90[ab]	20.01 ± 3.11[a]	20.05 ± 2.05[a]
Crude fat	4.78 ± 0.16[ab]	4.72 ± 0.00[a]	4.70 ± 0.00[a]
Total	95.63	99.05	97.15

Unit g/100 g

Value shown as mean ± standard deviation

[a–b] Means with the same superscripts in a row are not significantly different by Duncan's multiple range test ($P < 0.05$)

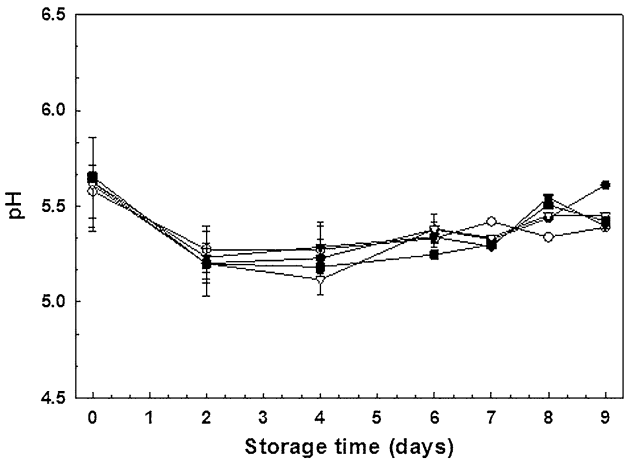

Fig. 1 Changes of pH in Hanwoo beef treated with UV radiation for various times during storage at 4 °C. *Dashed filled circles* control (without UV radiation), *dashed open circles* 5 min, *dashed filled down pointing triangles* 10 min, *dashed open down pointing triangles* 15 min, *dashed filled squares* 20 min

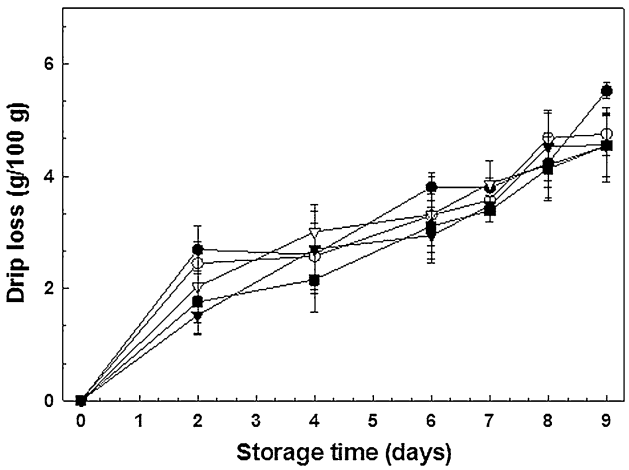

Fig. 2 Changes of drip loss in Hanwoo beef treated with UV radiation of various times during storage at 4 °C. *Dashed filled circles* control, *dashed open circles* 5 min, *dashed filled down pointing triangles* 10 min, *dashed open down pointing triangles* 15 min, *dashed filled squares* 20 min

The initial pH was 5.6–5.7. The pH levels of all of the samples from the initial 2 days of storage decreased and then slightly increased up to day 9 of storage. These results were consistent with those reported by Chung et al. (1997) in which pH decreased immediately after slaughter and increased gradually during storage at 5 °C. Energy is stored in muscles as glycogen that is formed under normal circumstances. However, in dying muscle glycogen is converted to lactic acid which decreases pH and causes the normally purple muscle to change in color to bright red or pink due to the accumulation of hydrogen ions (England et al. 2013) and metabolic heat production (Jacob and Hopkins 2014). The reason for the gradual increase in pH levels after 2 days of storage is believed to be an increase in amino acid and nitrogen compounds, along with protein degradation caused by the secretions of enzymes from aging muscles or microorganisms (Park et al. 1988; Kim et al. 2010). No significant pH difference was observed between the UV radiation time and the storage period ($P < 0.05$).

Drip loss

The changes in drip loss in beef treated with UV radiation during storage at 4 °C are shown in Fig. 2. The drip loss following 0, 5, 10, 15, and 20 min of UV radiation of beef increased significantly (2.70, 2.45, 1.52, 2.03, and 1.76 g/100 g, respectively) during 2 days of storage, and then steadily increased for 9 days of storage. According to the study by Wyrwisz et al. (2012), drip loss negatively correlates with the pH value; this conclusion was supported by our initial 2 day incubation results (see Fig. 1). No significant difference in drip loss was observed between the UV radiation and the storage time ($P < 0.05$). Drip loss is caused by the lateral shrinkage of myofibrils that expel water into the muscle's extracellular space. After slaughter, the inter-fiber bundles and individual fibers have large gaps which act as channels to transport these drips (Honikel et al. 1986; Huff-Lonergan and Lonergan 2007). The significant increase in drip loss in the initial 2 days of storage could be explained by the relatively high temperature during the initial storage period, even in the refrigerator. O'Keeffe and Hood (1980–1981) reported that drip loss at 0–5 °C is less than that at 5–10 °C. The cause of the temperature effect on drip loss is unknown, but it is probably due to a decrease in the viscosity of the drip (Marjan et al. 1998; Bekhit et al. 2007), which might lead to a change in the beef's quality.

Color

The results of changes in Hunter color values of the Hanwoo beef treated with varying durations of UV radiation times during storage at 4 °C are shown in Table 2. The L^* values (lightness) of all samples increased significantly during the 9 days of storage. These results were similar to studies performed by Yook et al. (1998) and Kim and Cheong (1999). The a^* values (redness) of all samples increased through day 6 of storage, but then decreased by day 9. The b^* values (yellowness) of all samples either did not significantly change or increased slightly over the 9 days of storage. A similar effect was observed by Yook et al. (1998). The L^*, a^*, and b^* values of non-radiated Hanwoo beef were significantly higher than those of UV-radiated beef. This could be explained by lipid oxidation and with the oxymyoglobin layer that forms on the beef's

Table 2 Changes of Hunter color values in Hanwoo beef treated with UV radiation for various times during storage at 4 °C

Storage time (days)	UV radiation time (min)				
	0	5	10	15	20
*L** value					
0	39.79^{aC}	38.98^{bD}	38.84^{bD}	38.01^{cD}	38.13^{cE}
2	39.82^{aC}	39.52^{aC}	39.30^{aC}	38.81^{bC}	38.83^{bD}
4	40.41^{aBC}	39.37^{bC}	39.30^{bC}	38.81^{cC}	38.83^{cD}
6	41.07^{aB}	41.05^{aB}	39.75^{bB}	39.35^{cB}	39.15^{dC}
8	41.07^{aB}	41.05^{aB}	40.57^{bA}	40.58^{bAB}	40.18^{cB}
9	42.55^{aA}	42.57^{aA}	40.71^{dA}	41.16^{bA}	41.03^{cA}
*a** value					
0	10.08^{aC}	9.90^{bB}	8.11^{eD}	8.57^{dA}	8.74^{cA}
2	10.10^{aC}	9.92^{bB}	8.63^{dAB}	9.77^{cBC}	9.92^{bBC}
4	10.10^{aC}	9.92^{bB}	8.63^{dAB}	9.77^{cBC}	9.92^{bBC}
6	10.80^{aB}	10.46^{cC}	10.78^{bC}	9.94^{eC}	10.19^{dC}
8	9.29^{aA}	9.77^{aB}	10.18^{aB}	9.46^{cB}	9.65^{bB}
9	9.15^{aA}	8.93^{bA}	8.96^{bA}	8.49^{cA}	8.45^{cA}
*b** value					
0	8.69^{aC}	8.10^{bB}	7.97^{cC}	7.94^{cD}	7.94^{cC}
2	8.93^{aB}	8.44^{cB}	8.61^{bB}	8.14^{dC}	8.07^{eB}
4	8.93^{aB}	8.44^{cB}	8.61^{bB}	8.14^{dC}	8.07^{eB}
6	9.64^{aA}	9.26^{bA}	8.59^{cB}	8.24^{dBC}	8.52^{cA}
8	9.77^{aA}	9.34^{bA}	9.17^{cA}	8.98^{dB}	9.18^{cD}
9	9.74^{aA}	9.20^{bA}	9.24^{bA}	8.91^{cA}	9.28^{bD}

[a–e] Means with the same superscripts in a row are not significantly different by Duncan's multiple range test ($P < 0.05$)

[A–D] Means with the same superscripts in a column are not significantly different by Duncan's multiple range test ($P < 0.05$)

surface (Mancini and Hunt 2005a, b). Myoglobin converts to oxymyoglobin when fresh meat is exposed to oxygen, which leads to a decrease in the bright red color by oxidation reduction after 6 days of storage. Midgley and Small (2006) reported that UV light has been associated with accelerated lipid oxidation and browning due to metmyoglobin formation.

Shear force

Figure 3 shows the changes in shear force of Hanwoo beef after being treated with UV radiation during storage. The shear force values for the 0, 5, 10, 15, and 20 min UV-radiated beef were 11.72, 11.96, 11.21, 11.51, and 11.26 kg/cm^2, respectively. No difference was observed between UV-radiated and non-radiated beef ($P < 0.05$). During the 9 days of storage, shear force decreased slightly to 9.16, 8.92, 9,66, 8.84, and 8.84 kg/cm^2 in the 0, 5, 10, 15, and 20 min UV radiation groups, respectively. Similarly, Kim and Cheong (1999) and Smith et al. (1971) reported decreased shear forces with increased storage times. The decrease in shear force could be induced from the longer sarcomere length and destruction of the Hanwoo beef muscle bundles during storage (Yook et al. 2001; Hwang et al. 2004).

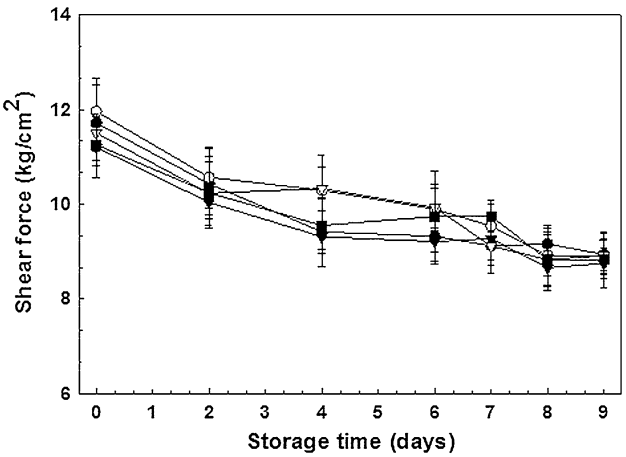

Fig. 3 Changes of shear force in Hanwoo beef treated with UV radiation for various times during storage at 4 °C. *Dashed filled circles* control, *dashed open circles* 5 min, *dashed filled down pointing triangles* 10 min, *dashed open down pointing triangles* 15 min, *dashed filled squares* 20 min

TBA values

One of the most important causes of beef deterioration is lipid oxidation, which affects fatty acids components. Particularly, polyunsaturated fatty acids are changed to peroxide and carbonyl compounds. The TBA test is a

colorimetric analysis in which absorbance is measured between the TBA and malonaldehyde reactions. TBA values could be closely related to increased unpleasant odors during meat storage (Yook et al. 1998) and lipid oxidation (Kusmider et al. 2002). The TBA values of Hanwoo beef treated with UV radiation increased steadily until day 7 of storage, and then increased significantly to 0.76, 0.82, 0.84, 0.85, and 0.87 in the 0, 5, 10, 15, and 20 min UV-radiated treatments, respectively (see Fig. 4). Previous research (Demeyer et al. 1974; Gandemer 2002) reported that fatty acids are degraded by lipase hydrolysis and microbial metabolism to produce peroxides and carbonyl compounds, aldehydes, ketones, and alcohols, which affect the taste and flavor of meat. TBA values in the tested meat increased significantly with storage time. The UV-radiated meat showed slightly higher ($P < 0.05$) TBA values during storage than those of non-radiated beef, which might be explained by the auto-oxidation of fat. Free radicals combine with oxygen to form hydroperoxide during UV radiation, which breaks down into various decomposition products such as aldehydes, as described above. Therefore, malonaldehyde accumulates as the major TBA-reactive substance (Cherian et al. 2002; Kanatt et al. 1997).

VBN

Meat deterioration during storage is mainly caused by microbial contamination during the slaughter process. A particularly unpleasant smell is produced by amines, ammonia, H_2S, mercaptan, indole, and skatole, which originate from amino acids. VBN was used to indicate protein deterioration during storage which indicates freshness of

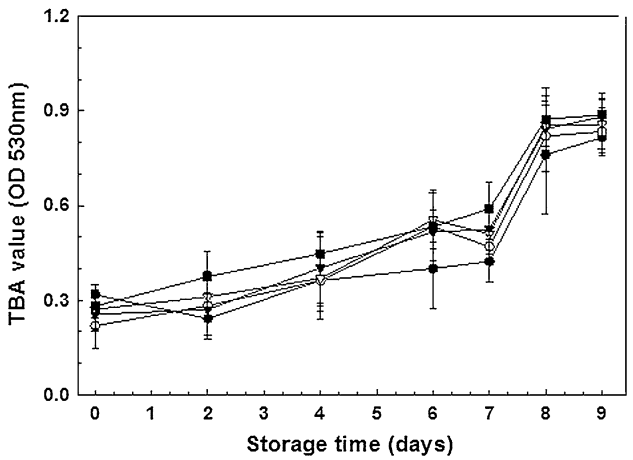

Fig. 4 Changes of TBA values in Hanwoo beef treated for various times with UV radiation during storage at 4 °C. *Dashed filled circles* control, *dashed open circles* 5 min, *dashed filled down pointing triangles* 10 min, *dashed open down pointing triangles* 15 min, *dashed filled squares* 20 min

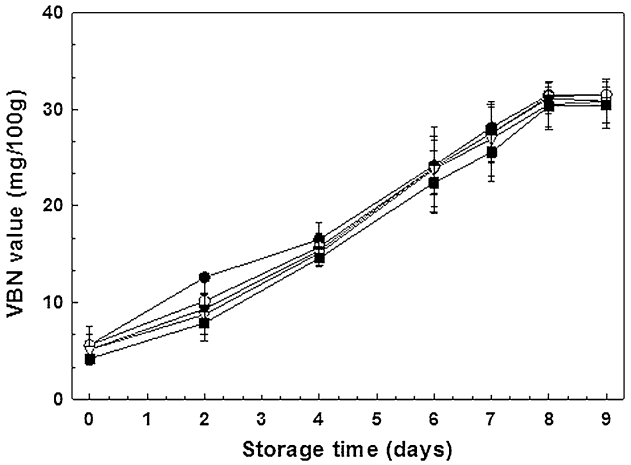

Fig. 5 Changes of VBN values in Hanwoo beef treated with UV radiation for various times during storage at 4 °C. *Dashed filled circles* control, *dashed open circles* 5 min, *dashed filled down pointing triangles* 10 min, *dashed open down pointing triangles* 15 min, *dashed filled squares* 20 min

meat product (Yook et al. 1998; Yun et al. 2012). The changes in VBN values in the Hanwoo beef treated after UV radiation are shown in Fig. 5. The VBN contents were <5.6 mg/100 g after radiation, which is similar to values found in a study by Yook et al. (1998). They observed <6 mg/100 g VBN content at the beginning of the Hanwoo beef's storage. VBN content increased rapidly after 6 days of storage (>20 mg/100 g). In general, a 20 mg/100 g VBN content is a non-edible status based on Korean Food Law (Yun et al. 2012). In the present study, non-radiated beef reached a 24.18 mg/100 g VBN content and 20 min UV-radiated beef reached 22.41 mg/100 g during 6 days of storage. No significant differences were observed in the VBN content among the various UV radiation times ($P < 0.05$). Therefore, protein degradation was not affected by UV radiation.

Sensory changes during storage

Table 3 shows the changes recorded from sensory evaluations of Hanwoo beef treated with UV radiation. Odor did not significantly change in the non-radiated and UV-radiated beef during 4 days of storage, and then it decreased significantly until 9 days of storage. The non-radiated beef showed less tenderness than the radiated beef. These results are consistent with the shear force results (see Fig. 3). This might be explained by increased cross linkage with actin (42 KD MW) and myosin (520 KD MW) after rigor mortis (Chung et al. 1997; Kim et al. 2014). No significant changes were observed in the color ($P < 0.05$). Succulence was lowest in non-radiated beef after 4 days of storage. However, succulence increased significantly in non-radiated beef after 4 days of storage. The overall acceptability

Table 3 Changes in the sensory evaluation (1: good, 4: moderate, 7: poor) of Hanwoo beef treated with UV radiation for various times during storage at 4 °C

Storage time (days)	UV radiation time (min)				
	0	5	10	15	20
Odor					
0	3.0^{A}	3.2^{A}	3.3^{A}	3.3^{A}	3.4^{A}
2	3.8^{AB}	3.9^{AB}	3.9^{AB}	4.0^{B}	4.0^{B}
4	4.0^{AB}	4.2^{AB}	4.2^{AB}	4.1^{B}	4.3^{BC}
6	4.9^{B}	4.8^{B}	4.5^{B}	4.6^{C}	4.5^{C}
7	5.4^{C}	4.5^{AB}	4.6^{B}	4.6^{C}	4.5^{C}
8	5.4^{C}	5.0^{B}	4.9^{BC}	4.8^{CD}	4.5^{C}
9	6.0^{D}	5.7^{C}	5.2^{C}	5.0^{D}	5.0^{D}
Tenderness					
0	2.1^{D}	2.1^{C}	2.6^{D}	2.5^{D}	2.4^{D}
2	3.0^{CD}	3.6^{B}	2.7^{D}	3.1^{C}	3.2^{C}
4	3.5^{BC}	3.9^{AB}	3.7^{C}	3.8^{B}	3.9^{BC}
6	4.2^{AB}	4.3^{AB}	4.4^{BC}	4.8^{A}	4.2^{B}
7	4.4^{AB}	4.5^{AB}	4.6^{B}	4.8^{A}	4.4^{B}
8	4.6^{A}	4.7^{AB}	4.7^{B}	4.9^{B}	5.2^{A}
9	5.0^{A}	5.2^{A}	5.2^{A}	5.1^{A}	5.2^{A}
Color					
0	2.1^{C}	2.1^{C}	2.5^{D}	2.0^{C}	2.2^{C}
2	3.5^{B}	3.6^{B}	3.3^{C}	3.4^{B}	3.6^{B}
4	3.9^{B}	3.9^{B}	4.0^{B}	3.6^{B}	3.9^{B}
6	4.6^{AB}	4.5^{AB}	4.5^{AB}	4.7^{A}	4.4^{AB}
7	4.7^{AB}	4.7^{AB}	5.0^{AB}	4.7^{A}	4.7^{A}
8	4.9^{A}	4.9^{A}	5.2^{A}	4.8^{A}	4.8^{A}
9	5.0^{A}	5.1^{A}	5.3^{A}	5.2^{A}	4.9^{A}
Succulence					
0	2.2^{C}	2.1^{C}	2.5^{C}	2.0^{C}	2.1^{C}
2	3.3^{BC}	3.1^{B}	3.7^{BC}	3.5^{B}	3.2^{BC}
4	3.7^{B}	4.0^{AB}	4.0^{B}	3.6^{B}	3.6^{B}
6	4.8^{A}	4.4^{A}	4.4^{B}	4.2^{AB}	3.7^{AB}
7	4.9^{A}	4.4^{A}	4.4^{B}	4.4^{A}	4.7^{A}
8	5.1^{A}	4.7^{A}	4.8^{AB}	4.9^{A}	4.8^{A}
9	5.3^{A}	4.9^{A}	5.4^{A}	4.9^{A}	4.8^{A}
Overall acceptability					
0	2.3^{D}	2.5^{C}	2.6^{C}	2.8^{C}	2.6^{C}
2	3.8^{C}	3.6^{B}	3.5^{B}	3.6^{B}	3.7^{B}
4	4.2^{B}	4.0^{AB}	3.6^{B}	4.2^{AB}	3.9^{B}
6	4.4^{B}	4.3^{AB}	4.3^{AB}	4.3^{AB}	4.0^{B}
7	4.9^{BC}	4.4^{AB}	4.4^{AB}	4.5^{A}	4.1^{B}
8	5.4^{A}	4.9^{A}	4.7^{A}	4.7^{A}	4.4^{AB}
9	5.6^{A}	4.9^{A}	4.8^{A}	4.8^{A}	4.7^{A}

$^{A–D}$ Means with the same superscripts in a column are not significantly different by Duncan's multiple range test ($P < 0.05$)

of non-radiated beef during initial storage was slightly better than that of UV-radiated beef. However, according to the increased storage time, the overall acceptability was better for UV-radiated beef than for non-radiated beef. This result indicates that the decay of UV-radiated beef was slower than that of non-radiated beef, and therefore caused a low preference.

References

AOAC (2006) Official methods of analysis, 15th edn. Association of Official Analytical Chemists, Washington, DC, pp 210–219

Assatarakul K, Churey JJ, Manns DC, Worobo RW (2012) Patulin reduction in apple juice from concentrate by UV radiation and comparison of kinetic degradation models between apple juice and apple cider. J Food Prot 75(4):717–724

Bekhit AED, Farouk MM, Cassidy L, Gilbert KV (2007) Effects of rigor temperature and electrical stimulation on venison quality. Meat Sci 75(4):564–574

Chan CF, Lien CY, Lai YC, Huang CL, Liao WC (2010) Influence of purple sweet potato extracts on the UV absorption properties of a cosmetic cream. J Cosmet Sci 61:333–341

Cherian G, Selvaraj RK, Goeger MP, Stitt PA (2002) Muscle fatty acid composition and thiobarbituric acid-reactive substances of broilers fed different cultivars of sorghum. Poult Sci 81:1415–1420

Cho SH, Park BY, Kim JH, Hwang IH, Kim JH, Lee JM (2005) Fatty acid profiles and sensory properties of *Longissimus dorsi*, Triceps brachii, and Semimembranosus muscle from Korean Hanwoo and Australian Angus beef. Asian Australas J Anim Sci 18:1786–1793

Choi HS, Yeo KM (1998) Foods quality assurance. Shim Gwang Press, Seoul, korea, p 141 (in Korean)

Choi YI, Kim YK, Lee CL (1995) Effect of packaging method and aging temperature on color, tenderness and storage characteristics of Korean beef. Korean Anim Sci 37:639–650

Chung MS, Kang BY, Kim YJ, Lee M (1997) Effect of γ-radiation on the aging of beef. Korean J Anim Sci 39:297–308

Demeyer D, Hoozaee J, Meadom H (1974) Specificity of lipolysis during dry sausage ripening. J Food Sci 39:293–296

England EM, Scheffier TL, Kasten SC, Matameh SK, Gerrard DE (2013) Exploring the unknowns involved in the transformation of muscle to meat. Meat Sci 95(4):837–843

Gailunas KM (2003) Use of ultraviolet light for the inactivation of listeria monocytogenes and lactic acid bacteria species in recycled chill brines. Thesis, Food Science and Technology, Virginia Polytechnic Institute and State University

Gandemer G (2002) Lipids in muscles and adipose tissues, changes during processing and sensory properties of meat products. Meat Sci 62:309–321

Han SW, Lee BO (2010) A study on the purchasing behaviors of consumers for domestic and imported beef in Korea. J Agric Life Sci 22:73–89

Harrington WO, Claude HH (1968) Reduction of the microbial population apple cider by ultraviolet irradiation. Food Technol 22:1451–1454

Honikel, KO, Kim, CJ, and Hamm R (1986) Sarcomere shortening of prerigor muscles and it influence on drip loss. Meat Sci 16:267–282

Huang YW, Toledo R (1982) Effect of high doses of high and low intensity UV irradiation on the growth of microbial counts and storage-life of fish. J Food Sci 47:1667–1670

Huff-Lonergan E, Lonergan SM (2007) New frontiers in understanding drip loss in port: recent insights on the role of postmortem muscle biochemistry. J Anim Breed Genet 124:19–26

Hwang IH, Park BY, Cho SH, Lee JM (2004) Effects of muscle shortening and proteolysis on Warner–Bratzler shear force in beef longissimus and semitendinosus. Meat Sci 68(3):497–505

Jacob RH, Hopkins DL (2014) Techniques to reduce the temperature of beef muscle early in the post mortem period—a review. Anim Prod Sci 54:482–493

Jo C, Cho SH, Chang J, Nam KC (2012) Key to production and processing of Hanwoo beef: a perspective of tradition and science. Anim Front 2(4):32–38

Kanatt SR, Paul P, D'souza SF, Thomas P (1997) Effect of gamma radiation on the lipid peroxidation in chicken, lamb, and buffalo meat during chilled storage. J Food Saf 17:283–294

Kim YJ, Cheong JH (1999) Effect of packaging methods on the shelf-life of chilled Korean native beef. J Agric Sci Technol 34:75–81

Kim JB, Lee C (2000) Historical look at the genetic improvement in Korean cattle: review. Asian Australas J Anim Sci 13:1467–1481

Kim CJ, Suck JS, Ko WS, Lee ES (1994) Studies on the cold and frozen storage for the production of high quality meat of Korean native cattle II: effects of cold and frozen storage on the drip, storage loss and cooking loss in Korean native cattle. J Food Sci 14:151–154

Kim YH, Lonergan SM, Huff-Lonergan E (2010) Protein denaturing conditions in beef deep semimembranosus muscle results in limited μ-calpain activation and protein degradation. Meat Sci 86:883–887

Kim YHB, Warner RD, Rosenvold K (2014) Influence of high pre-rigor temperature and fast pH fall on muscle proteins and meat quality: a review. Anim Prod Sci 54:375–395

Kuo F, Carey JB, Ricke SC (1997) UV radiation of shell eggs: effect on populations of aerobes, molds, and inoculated *Salmonella typhimurium*. J Food Prot 6:610–737

Kusmider EA, Sebranek JG, Lonergan SM, Honeyman MS (2002) Effects of carbon monoxide packaging on color and lipid stability of irradiated ground beef. J Food Sci 67(9):3463–3468

Lee KJ, Cho MS (2012) Transition of Korean meat consumption and consumption trends after modern times—focused on beef and port. Korean J Food Cult 27(5):422–433

Lu JY, Stevens C, Yakubu P, Loretan PA (1987) Gamma, lectron beam and ultraviolet radiation on control of storage rots and quality of Walla Walla onions. J Food Process Preserv 12:53–62

Mancini RA, Hunt MC (2005) Current research in meat color. Meat Sci 71(1):100–121

Manzocco L, Pieve SD, Maifreni M (2011) Impact of UV-C light on safety and quality of fresh-cut melon. Innov Food Sci Emerg Technol 12:13–17

Marjan JAH, Frans JMS, Jan GVL (1998) The effect of storage temperature on drip loss from fresh beef. J Sci Food Agric 78:522–526

Midgley J, Small A (2006) Review of new and emerging technologies for red meat safety. Meat Livest Aust Final Rep Food Saf PRMS 083:2–72

O'Keeffe M, Hood DE (1980–1981) Anoxic storage of fresh beef. 2: Color stability and weight loss. Meat Sci 5:267–281

Park GB, Kang SH, Kim YJ, Lee HG, Kim YH (1988) Changes in meat protein of Korean native goats meat during postmortem storage. Korean J Anim Sci 30:123–129

Perez-Gregorio MR, Gonzalez-Barreiro C, Rial-Otero R, Simal-Gandara J (2011) Comparison of sanitizing technologies on the quality appearance and antioxidant levels in onion slices. Food Control 22:2052–2058

Ryeong MSI (1996) The UVO-type humidification cooling sterilizer. Food Ind 73–78

SAS Institute, Inc (2003) SAS User's Guide: Statistics, SAS Institute, Cary, NC, USA

Smith GC, Arango TC, Carpenter ZL (1971) Effects of physical and mechanical treatment on the tenderness of beef longisimuss. J Food Sci 36:445–449

Stevens C, Khan VA, Tang AY, Lu JY (1990) The effect of ultraviolet radiation on mold rots and nutrients of stored sweet potatoes. J Food Prot 53(3):223–226

Sucre E, Vidussi F, Mostajir B, Charmantier G, Lorin-Nebel C (2012) Impact of ultraviolet-B radiation on planktonic fish larvae: alternation of the osmoregulatory function. Aquat Toxicol 109:194–201

Wilson CL, Ghaouth AE, Upchurch B, Stevens C, Khan V, Droby S, Chalutz E (1997) Using an online UV-C apparatus to treat harvested fruit for controlling postharvest decay. Hort Technol 7(3):278–281

Witte VC, Gary FK, Milton EB (1970) A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. J Food Sci 35:582–585

Wyrwisz J, Poltorak A, Zalewska M, Zaremba R, Wierzbicka A (2012) Analysis of relationship between basic composition, pH, and physical properties of selected bovine muscles. Bull Vet Inst Pulawy 56:403–409

Yi YB, Sung SG (1984) Meat and Meat Product Analysis. Sunjin Munhwasa, Seoul, Korea, pp 144–145 (in Korean)

Yook HS, Lee JW, Lee KH, Kim S, Byun MW (1998) Effects of gamma radiation on pigments of beef. Korean J Food Sci Technol 30:1184–1188

Yook HS, Lee JW, Lee KH, Kim MK, Song CW, Byun MW (2001) Effect of gamma radiation on the microstructure and post mortem anaerobic metabolism of bovine muscle. Radiat Phys Chem 61(2):163–169

Yun H, Lee KH, Lee HJ, Lee JW, Ahn DU, Jo C (2012) Effect of high-dose irradiation on quality characteristics of ready-to-eat chicken breast. Radiat Phys Chem 81(8):1107–1110