Inactivation of *Salmonella* Typhimurium and *Escherichia coli* O157:H7 on black pepper powder using UV-C, UV-A and TiO$_2$ coating

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**Abstract** This study was conducted to measure the inactivation characteristics of UVs and TiO$_2$ against *Salmonella* Typhimurium and *Escherichia coli* O157:H7 on black pepper powder. The sample was irradiated by UV-A and UV-C combined with TiO$_2$ coating. After treatment, microbial and physicochemical analysis was carried out. Among various sterilization conditions, the largest number of pathogen in black pepper powder was inactivated by UV-A and UV-C combined with TiO$_2$ coating. The microbial count of black pepper powder treated simultaneously with UV-A and UV-C was less than that of black pepper powder treated with alone. The inactivation effect of UV-A and UV-C was increased when TiO$_2$ coating was combined. Moisture content was decreased with increasing treatment time, but color did not change. In this study, it was indicated that the combined treatment of UV-C, UV-A and TiO$_2$ coating was effective for reducing *S*. Typhimurium and *E. coli* O157:H7 on black pepper powder.

**Keywords** UV-C · UV-A · TiO$_2$ coating · Black pepper powder · Inactivation effect

**Introduction**

In recent years, consumer’s interest in natural flavor and taste has increased, and research on non-heat treatment technology to ensure food quality and safety has been actively conducted (Knorr et al., 2011; Ojha et al., 2015). Titanium dioxide (TiO$_2$) is a photocatalyst that is used to make an antimicrobial surface and has proved to be effective for sterilizing a wide range of microorganisms, including endospores (Foster et al., 2011). TiO$_2$ does not produce byproducts, can be used repeatedly, and has the advantages of being stable and non-toxic under UV irradiation. (Yemmireddy and Hung, 2015). TiO$_2$ has also been approved by the American Food and Drug Administration for use in human food, drugs, cosmetics, and food contact materials (Chawengkijwanich and Hayata, 2008). The mechanism of action of TiO$_2$ is due to the production of reactive oxygen species (ROS) with strong oxidizing power when UV light is irradiated at wavelengths of less than 385 nm (Maness et al., 1999). When microorganisms are exposed to -O$_2$ and -OH produced by photocatalyst, oxidative damage occurs in cell walls, cell membranes, DNA, and RNA (Blake et al., 1999). The oxidation of unsaturated phospholipids destroys the cell membrane, and the increase of ion permeability induces cell death by inducing oxidation of the internal cellular components (Alrousan et al., 2009).

Ultraviolet rays have a antimicrobial effect against many kinds of microorganisms including viruses (Guerrero Beltrán and Barbosa-Cnovas, 2004) and are used to sterilize air, water, and surfaces of food or cooking utensils (Gayán et al., 2011). UV-C is a light with a wavelength of 200–270 nm, which is readily absorbed by DNA, leading to the production of a large amount of pyrimidine dimers. The pyrimidine dimers formed by the absorption of UV-C
into DNA kills cells by interfering with DNA transfer and replication, making UV-C effective in sterilizing microorganisms. (Chevremont et al., 2012). UV-C does not create chemical residues, has low cost maintenance, and does not change quality because it is dry and cold processes (Guerrero-Beltrán and Barbosa-Cánovas, 2004). UV-A has a wavelength of 320–400 nm that induces the formation of active substances such as peroxide, which has a inactivation effect on the survival of microorganisms (Oppezzo and Pizarro, 2001). UV-A causes cell membrane damage due to long wavelengths, and shows lethal effects against microorganisms (Bintsis et al., 2000). Recent studies have shown that the antimicrobial effect of combined treatment with UV-C and UV-A is more effective than the effect of using UV-C or UV-A alone (Chevremont et al., 2012).

Black pepper is one of the most important and widely used spices in the world, and about 315,000–320,000 tons of the pepper are produced in 26 countries (Peter, 2006). However, Boer et al. found that black pepper showed a high level of microbial contamination above 10^7 CFU/g (De Boer et al., 1985). Black pepper is used as a spice to enhance taste and aroma in various dishes. Therefore, if spices such as black pepper are contaminated with bacterial pathogens, pathogens can easily enter food and cause food poisoning (McKee, 1995). Salmonella Typhimurium and Escherichia coli O157:H7 are the most frequently reported pathogens causing food poisoning and life-threatening diseases (Tarr, 1995; Zweifel and Stephan, 2012).

Salmonella Typhimurium causes salmonellosis (Alley et al., 2002) and E. coli O157:H7 cause diarrhea and hemolytic uremic syndrome disease after infection (Besser et al., 1993). Animal manure is a common carrier of pathogens such as S. Typhimurium and E. coli O157:H7, and black pepper grown on the ground can be infected with pathogens due to animal manure (Islam et al., 2004). It was reported that the cause of a large-scale salmonella infection in the United States from July 2009 to April 2010 was contaminated pepper added to salami products (Julian et al., 2009).

The inactivation effects of TiO₂ coating, UV-A, and UV-C against S. Typhimurium and E. coli O157:H7 on black pepper powder have not been previously reported. Therefore, this study proposed treatment combined with TiO₂ coating, UV-A, and UV-C to inhibit S. Typhimurium and E. coli O157:H7 growth on black pepper powder without heating.

### Materials and methods

#### Bacterial strains of S. Typhimurium and E. coli O157:H7

Three strains of Salmonella Typhimurium (ATCC 6994, 14028, 19585) and three strains of Escherichia coli O157:H7 (ATCC 43894, 43895, 35150) were obtained from Korean Collection for Type Cultures. All strains were stored at −80 °C in stock form. Stocks were prepared by mixing 0.5 mL of bacteria culture and 0.5 mL of 100% glycerol. The strains were cultured in tryptic soy broth (TSB; Difco Co., Franklin Lakes, NJ, USA) before use.

#### Bacteria culture preparation

Three strains of S. Typhimurium and three strains of E. coli O157:H7 were each added to 10 mL of TSB and incubated at 37 °C for 9 h. After incubation, 0.1 mL of the culture broth was inoculated into 10 mL of another TSB and cultured at 37 °C for 18 h again. The culture broth was centrifuged at 9000×g for 20 min at 4 °C, and the resulting pellet was resuspended in 5 mL of 0.85% saline (8.5 g/L sodium chloride; Sigma–Aldrich Corp., St. Louis, Mo., USA) (washing step). The washing step was repeated two more times. In the process, cocktails of bacterial cultures were performed between the same strains. Finally, the pellet was resuspended using 30 mL of 0.85% saline and used for experiment.

#### Sample preparation and inoculation

Black pepper powder (BPP) was obtained a bulk packaged in a pouch from local market and used for the experiment. The BPP was filtered with a 35-mesh sieve, and the size of the pepper powder was less than 35 mesh. The pepper powder of 150 g was placed in a sterile bag (Whirl–pak; 19.30 cm, Nasco, Fort Atkinson, WI, USA), and was added 5 mL of the bacterial culture for inoculation. And then, BPP in the bag was massaged by hand for 2 min and was dried in a biosafety hood for 1 h. Finally, about 10^5–10^6 CFU/g of S. Typhimurium and E. coli O157:H7 was inoculated on BPP.

#### System combined with UV-A, UV-C, and roaster-coated TiO₂ and treatment

All treatments were performed in a biosafety hood built-in air circulation system to prevent heat accumulation and microbial contamination. A roaster machine (MK-300, Miko Electrical Co., Ltd., Foshan, Guangdong PR, China), G40T10 Germicidal UV-C lamp (253.7 nm, 40 W,
SANKYO DENKI Co., Ltd., Kanagawa, Japan), and F40T10 Blacklight UV-A lamp (352 nm, 40 W, SANKYO DENKI Co., Ltd.) were installed in the biosafety hood.

To make a TiO\textsubscript{2} paste, TiO\textsubscript{2} powder (Aeroxide\textsuperscript{®} TiO\textsubscript{2} P25; 21 nm, Defussa Co., Germany) of 5 g was added to 45 mL of polycrylic (MinWax\textsuperscript{®} Water based polyacrylic; MinWax co., USA) and stirred for 1 h. After stirring, the solution was sonicated for 1 h. 5 mL of the prepared TiO\textsubscript{2} paste was coated once on Glad plastic wrap (Glad Food Plastic Wrap, width 30 cm, length 43.4 cm, United States) using a brush, and the TiO\textsubscript{2}-coated plastic wrap was attached to top surface of the roaster machine for TiO\textsubscript{2}-coating treatment.

The BPP was treated by UV-A (length 119.8 cm, lamp diameter 32 mm) and UV-C (length 119.8 cm, lamp diameter 32 mm) on the roaster machine (diameter 24 cm, depth 3.5 cm). The samples were placed 6 cm away from the UV lamp and the roaster machine continuously mixed the samples. The wavelengths of the UV-A and the UV-C installed in the biosafety hood were 352 and 253.7 nm, respectively, and the irradiation dose was 1.11 W/cm\textsuperscript{2}.

UV-A and UV-C were treated alone or in combination for 0, 30, 60, 90, 120, 150, and 180 min. Two UV lamps were used for each treatment. One UV-A lamp and one UV-C lamp were used when combining UV-A and UV-C.

Microbial analysis and injured cell enumeration

Treated BPP of 10 g and 90 mL of sterilized 0.85% saline put into a sterile bag and was homogenized for 2 min by a stomacher (Laboratory Blender Stomacher 400; Seward, MO, USA). The sample of 1 mL was serially diluted with 0.85% physiological saline, and then plated on each selective medium. To detect for \textit{S}. Typhimurium and \textit{E. coli} O157:H7, Xylose-Lysine-Deoxycholate agar (XLD agar; Difco, Becton–Dickinson Co., Sparks, MD) and Sorbitol MacConkey agar (SMac agar; Oxoid, Hampshire, UK) were used, respectively. The homogenized sample solution was incubated on selective agar at 37 °C for 24–48 h and the colonies formed on the plates were counted.

The overlay (OV) method was used to measure the population of injured cells caused by UV-A, UV-C, and TiO\textsubscript{2} coatings (Lee and Kang, 2001). Tryptone soya agar (TSA; Oxoid, Hampshire, UK) was used as a nutrient medium to recover injured \textit{S}. Typhimurium and \textit{E. coli} O157:H7. The diluted sample suspension was plated on TSA, and the plate was cultured at 37 °C for 2 h. Then, 7–8 mL of XLD agar and SMac agar were poured on the plate (Kang and Siragusa, 1999). When the agar was hard, the plate was incubated at 37 °C for 24–48 h, and then and the colonies formed were counted. The colony number was calculated by Ukuku in terms of % population of injured cells via the following formula (Ukuku and Geveke, 2010):

\[
\frac{1}{2} \left( \frac{\text{colonies on selective agar}}{\text{counts on agar in OV method}} \right) \times 100
\]

Moisture measurement and color measurement

OHAUS MB 45 Moisture Analyzers (MB 45; OHAUS, NJ, USA) were used to measure the moisture content of BPP. Moisture content of BPP were measured at 0, 30, 60, 90, 120, 150, and 180 min during treatment. When each treatment was end, 2 g of BPP was put on an aluminum dish and was measured the moisture content by heating at 140 °C for 10 min.

A colorimeter (CR-400 Chroma Meter; Konica Minolta Sensing, Inc., Japan) was used to determine the effect of UV-A, UV-C and TiO\textsubscript{2} coatings on the color of BPP. To measure the color change of BPP, L\textsuperscript{*}, a\textsuperscript{*} and b\textsuperscript{*} values were measured using 2 g of BPP before and after treatment.

Statistical analysis

All experiments were repeated three times to calculate average number of microorganisms and results were converted to log CFU/g. IBM SPSS statistics program (version 23, IBM Corp., USA) statistically performed the analysis of variance on calculated results. Duncan’s multiple range test separated the mean values of results. This study concluded that there was a significant difference between the samples when \( p < 0.05 \).

Results and discussion

Antimicrobial effect of UV-A, UV-C and TiO\textsubscript{2} coating on BPP

The inactivation effect of UV-A, UV-C and TiO\textsubscript{2} coating against \textit{S}. Typhimurium on BPP is shown in Fig. 1. In Fig. 1(A) is a group treated without TiO\textsubscript{2}, and (B) is a group treated with TiO\textsubscript{2}. The initial concentration of \textit{S}. Typhimurium on BPP was 5.42 ± 0.11 log CFU/g. UV-A alone (UA) and UV-C alone (UC) inhibited 1.04 and 0.93 log CFU/g of \textit{S}. Typhimurium, respectively. When UV-A and UV-C were applied in combination (UAC), 1.74 log CFU/g of \textit{S}. Typhimurium was inactivated. The combined treatment of TiO\textsubscript{2} and UV-A (TUA) and the combined treatment of TiO\textsubscript{2} and UV-C (TUC) reduced about 1.65 and 1.08 log CFU/g of \textit{S}. Typhimurium, respectively. When TiO\textsubscript{2}, UV-A and UV-C were
treated together (TUAC) for 180 min, 2.17 log CFU/g of *S. Typhimurium* was reduced. The inactivation effect of UA was significantly (*p* < 0.05) higher than that of UC when treated for 150 min, and UAC was significantly (*p* < 0.05) higher than UA and UC after 60 min of treatment. When TUA or TUC was applied for more than 90 min, *S. Typhimurium* on BPP was significantly (*p* < 0.05) different from the control group (R-con) that was treated using only a roaster machine. When TUAC was treated for 30 min, the inactivation effect was significantly (*p* < 0.05) higher than that of TUA and TUC, and TUAC reduced most *S. Typhimurium* on BPP.

TUA showed a higher inactivation effect than UA against *S. Typhimurium* on BPP, and showed a significant (*p < 0.05*) difference between 90 and 180 min. When treated for 30 min, TUC reduced significantly (*p < 0.05*) more *S. Typhimurium* than UC, but there was no significant (*p > 0.05*) difference between the inactivation effects of the two treatments thereafter. *Salmonella Typhimurium* was more inactivated by the treatment combined with UV-A and UV-C than treatment using UV-A and UV-C alone. In addition, TiO2 coatings significantly (*p < 0.05*) increased the inactivation effects of UV-A and UV-C against *S. Typhimurium* on BPP.

The inactivation effect of UV-A, UV-C, and TiO2 coating against *E. coli* O157:H7 on BPP is shown in Fig. 2. In Fig. 2(A) is a group treated without TiO2, and (B) is a group treated with TiO2. The initial concentration of *E. coli* O157:H7 on BPP was 6.64 ± 0.10 log CFU/g.

UA and UC inhibited *E. coli* O157:H7 by 1.13 and 1.54 log CFU/g, respectively. UAC inactivated 1.46 log CFU/g of *E. coli* O157:H7 for 180 min. For 180 min, TUA and TUC reduced *E. coli* O157:H7 by 1.46 and 1.80 log CFU/g, respectively. When TUAC was applied for 180 min, *E. coli* O157:H7 on BPP was inactivated by 1.74 log CFU/g. TUA inhibited significantly (*p < 0.05*) more *E. coli* O157:H7 than UA for 120 min. A number of *E. coli* O157:H7 was significantly (*p < 0.05*) reduced by UC and TUC compared with R-con, and *E. coli* O157:H7 was more inactivated by TUC than UC at 180 min. However, there was no significant (*p > 0.05*) difference between R-con, UAC, and TUAC until 30 min. However, TUAC showed a similar or significantly (*p < 0.05*) better inactivation effect than UAC after 60 min.

UC showed a bactericidal effect against *E. coli* O157:H7 similar to that of TUC. The BPP treated by UAC had significantly (*p < 0.05*) fewer *E. coli* O157:H7 than the pepper powder of R-con, and TUAC inactivated significantly (*p < 0.05*) more *E. coli* O157:H7 than the R-con from 60 to 180 min. The inactivation effect of UV-A and UV-C against *E. coli* O157:H7 was enhanced by the TiO2 coating.

The inactivation effect of UA, UC and UAC against *S. Typhimurium* was increased with 0.67, 0.48, and 0.03 log CFU/g for 180 min by TiO2 coating, respectively. The inactivation effect of UA, UC, and UAC against *E. coli* O157:H7 was increased with 0.33, 0.25, and 0.27 log CFU/g, when also treated with TiO2 coating for 180 min. According to the results, it was confirmed that the
Inactivation effect of UV combined with TiO$_2$ coating was increased compared with UV alone treatment.

Production of injured cell by UV-A, UV-C irradiation and TiO$_2$ coating

The number of injured $S$. Typhimurium and $E$. coli O157:H7 cells on BPP after treatment with UV-A, UV-C, and TiO$_2$ coating is shown in Fig. 3. In Fig. 3(A) is the number of injured $S$. Typhimurium, and (B) is the number of injured $E$. coli O157:H7. Immediately after inoculation, 4.70% and 2.46% of the $S$. Typhimurium and $E$. coli O157:H7 cells were injured, respectively. On average, $S$. Typhimurium and $E$. coli O157:H7 resulted in 2.77% and 3.89% injured cells, respectively, when the samples were continuously mixed using the roaster machine without any treatment (R-con).

UA and TUA produced an average of 3.95% and 6.20% injured cells, respectively, for $S$. Typhimurium on BPP. In the pepper powder treated with UC and TUC, the average number of injured $S$. Typhimurium was 3.24% and 2.43%. In the UAC- and TUAC-treated BPP, there was an average of 5.26% and 6.55% of injured $S$. Typhimurium cells. In the pepper treated with UA, UC, and UAC, the average inactivation effect of UV combined with TiO$_2$ coating was increased compared with UV alone treatment.

Fig. 2 Inactivation effect of UV-A, UV-C, and TiO$_2$ coating against $E$. coli O157:H7 inoculated on black pepper powder for 0, 30, 60, 90, 120, 150, and 180 min. Mean ± standard deviation obtained in two experiments, one of two experiments in duplicated (n = 3). The treatment involving TiO$_2$ coating is (A), and the treatment excluding TiO$_2$ coating is (B). Different capital letters indicate significant differences ($p < 0.05$) among treatments for each time. 1R-con means control group that was treated using only a roaster machine. 2UA means a group that was treated by UV-A alone. 3UC means a group that was treated by UV-C alone. 4UAC means a group that was treated by UV-A and UV-C simultaneously.

Fig. 3 Average number of injured cell of $S$. Typhimurium (A) and $E$. coli O157:H7 (B) produced by UV-A, UV-C, and TiO$_2$ coating during treatment. Mean ± standard deviation obtained in two experiments, one of two experiments in duplicated (n = 3). 1R-con means control group that was treated using only a roaster machine. 2UA means a group that was treated by UV-A alone. 3TUA means a group that was treated by UV-C and TiO$_2$. 4UC means a group that was treated by UV-C alone. 5TUC means a group that was treated by UV-C and TiO$_2$. 6UAC means a group that was treated by UV-A and UV-C simultaneously. 7TUAC means a group that was simultaneously treated by UV-A, UV-C, and TiO$_2$
number of injured *E. coli* O157:H7 was 3.52%, 3.45%, and 2.95%, respectively. When treated with TUA, TUC, and TUAC, 3.74%, 3.63%, and 2.38% of *E. coli* O157:H7 were injured on average.

All treatments except for the TUC treatment formed injured cells of *S. Typhimurium* more than R-con on average. On the other hand, the injured *E. coli* O157:H7 produced by UA, TUA, UC, TUC, UAC, and TUAC was on average less than that produced by R-con. However, on both *S. Typhimurium* and *E. coli* O157:H7, there was no significant (*p > 0.05*) difference between productions of the injured cells depending on the treatments. This result shows that all treatments including UV-A, UV-C and TiO2 coating do not affect production of the injured cell on BPP.

**Moisture changes of BPP during UV-A and UV-C irradiation combined with TiO2 coating**

The changes in the moisture content of BPP depending on the length of treatments using UV-A, UV-C, and TiO2 coatings are shown in Fig. 4. The initial moisture content of the pepper powder inoculated with *S. Typhimurium* and *E. coli* O157:H7 was 12.90 ± 0.08%. The moisture content of BPP treated by R-con for 180 min decreased by 2.61%.

When UA and TUA were applied for 180 min, the moisture content of BPP decreased by 3.81% and 3.69%, respectively. UC and TUC decreased the moisture content of BPP by 3.20% and 3.11%, respectively, for 180 min. The moisture content of BPP treated with UAC and TUAC for 180 min decreased by 3.66% and 3.60%, respectively. The moisture content of BPP treated by UA was significantly (*p < 0.05*) lower than that of R-con after 60 min, and TUA significantly (*p < 0.05*) decreased the moisture content to below that of R-con after 90 min. UC and TUC were significantly (*p < 0.05*) different from R-con after 90 min. Compared with R-con, UAC and TUAC had significantly (*p < 0.05*) lower moisture content after 30 min. UA, TUA, UC, TUC, UAC, and TUAC treatments for 180 min reduced the moisture content by 1.21%, 1.09%, 0.59%, 0.50%, 1.06%, and 1.00%, respectively.

The UC and TUC treatments for 180 min had significantly (*p < 0.05*) fewer differences with R-con, compared with other treatments. UCA- and TUCA-treated BPP had higher moisture content than UA- and TUA-treated BPP. These results show that UV-C is more effective than UV-A in maintaining the moisture content of BPP. In addition, it was confirmed that the treatment combined with TiO2 coating kept a higher moisture content than the treatment without TiO2 coating. These results indicate that TiO2 coating helps preserve the moisture content of BPP.

**Color changes of BPP during UV-A and UV-C irradiation combined with TiO2 coating**

Table 1 shows the effects of UV-A and UV-C treatments combined with TiO2 coating on the color of BPP. The L*,
Table 1 Change of color (L*, a*, b*) of BPP by UV-A, UV-C, and TiO₂ coating according to treatment time.

| Color value | Time (min) | R-con² | UA³ | TUA⁴ | UC⁵ | TUC⁶ | UAC⁷ | TUAC⁸ |
|-------------|------------|--------|-----|------|-----|------|------|-------|
| L           | 0          | 53.55 ± 0.36³ | 53.55 ± 0.36³ | 53.55 ± 0.36³ | 53.55 ± 0.36³ | 53.55 ± 0.36³ | 53.55 ± 0.36³ | 53.55 ± 0.36³ |
|             | 30         | 51.13 ± 0.99⁵ | 52.57 ± 0.32⁶ | 52.23 ± 0.32⁶ | 51.66 ± 0.51⁷ | 62.19 ± 0.57⁷ | 51.00 ± 0.32⁸ | 50.99 ± 0.32⁸ |
|             | 60         | 50.65 ± 0.63⁵ | 52.08 ± 0.04⁵ | 51.99 ± 0.40⁹ | 50.96 ± 0.42³ | 51.99 ± 0.60⁹ | 51.90 ± 0.55³ | 50.43 ± 0.47³ |
|             | 90         | 50.06 ± 0.78⁵ | 50.67 ± 0.84⁶ | 51.66 ± 0.06⁶ | 52.50 ± 0.49⁷ | 50.39 ± 0.34⁷ | 51.20 ± 0.55⁷ | 51.02 ± 0.13³ |
|             | 120        | 52.50 ± 0.40⁴ | 51.51 ± 0.43⁴ | 52.21 ± 0.51⁵ | 51.85 ± 0.25⁶ | 51.36 ± 0.44⁶ | 51.51 ± 0.27⁶ | 51.03 ± 0.84³ |
|             | 150        | 52.19 ± 0.74⁴ | 50.86 ± 0.39⁴ | 51.26 ± 0.50⁸ | 51.58 ± 0.23⁸ | 52.00 ± 0.27⁸ | 50.95 ± 0.76⁸ | 52.44 ± 0.44⁸ |
|             | 180        | 51.31 ± 0.25⁴ | 48.72 ± 0.39⁹ | 53.48 ± 0.42³ | 52.41 ± 0.28³ | 55.20 ± 0.57³ | 52.44 ± 0.37³ | 53.59 ± 0.22³ |
| a           | 0          | 2.16 ± 0.08³ | 2.16 ± 0.05³ | 2.16 ± 0.05³ | 2.16 ± 0.05³ | 2.16 ± 0.05³ | 2.16 ± 0.05³ | 2.16 ± 0.05³ |
|             | 30         | 1.97 ± 0.14³ | 2.09 ± 0.07⁴ | 2.13 ± 0.02⁴ | 2.07 ± 0.05⁵ | 2.09 ± 0.03⁷ | 2.10 ± 0.06⁷ | 2.07 ± 0.04⁷ |
|             | 60         | 2.07 ± 0.04³ | 2.11 ± 0.01³ | 1.94 ± 0.03⁵ | 2.19 ± 0.16³ | 2.19 ± 0.05⁵ | 2.07 ± 0.06⁵ | 2.00 ± 0.02³ |
|             | 90         | 2.06 ± 0.06³ | 2.12 ± 0.02⁷ | 2.10 ± 0.03⁷ | 2.05 ± 0.08⁷ | 1.96 ± 0.09⁷ | 2.03 ± 0.03⁷ | 2.07 ± 0.02³ |
|             | 120        | 1.99 ± 0.07³ | 2.17 ± 0.07⁷ | 2.17 ± 0.02⁷ | 2.13 ± 0.05⁷ | 2.02 ± 0.02⁷ | 2.09 ± 0.04⁷ | 2.12 ± 0.01³ |
|             | 150        | 1.95 ± 0.01³ | 2.22 ± 0.04⁷ | 2.10 ± 0.04⁷ | 2.19 ± 0.04⁷ | 2.06 ± 0.01³ | 2.19 ± 0.02³ | 2.26 ± 0.02³ |
|             | 180        | 2.15 ± 0.03³ | 2.22 ± 0.04³ | 2.15 ± 0.06⁷ | 2.18 ± 0.01⁷ | 2.19 ± 0.04⁷ | 2.12 ± 0.01³ | 2.16 ± 0.01³ |
| b           | 0          | 10.84 ± 0.11³ | 10.84 ± 0.11³ | 10.84 ± 0.11³ | 10.84 ± 0.11³ | 10.84 ± 0.11³ | 10.84 ± 0.11³ | 10.84 ± 0.11³ |
|             | 30         | 10.21 ± 0.39³ | 10.49 ± 0.11³ | 10.65 ± 0.08³ | 10.66 ± 0.13³ | 10.44 ± 0.30³ | 9.96 ± 0.20³ | 10.24 ± 0.19³ |
|             | 60         | 9.86 ± 0.28³ | 10.55 ± 0.06³ | 10.32 ± 0.09³ | 10.15 ± 0.30³ | 10.73 ± 0.14³ | 10.19 ± 0.20³ | 9.84 ± 0.15³ |
|             | 90         | 9.89 ± 0.38³ | 10.19 ± 0.38³ | 10.25 ± 0.04³ | 10.75 ± 0.11³ | 9.64 ± 0.17³ | 10.24 ± 0.32³ | 10.42 ± 0.11³ |
|             | 120        | 10.65 ± 0.23³ | 10.10 ± 0.43³ | 11.17 ± 0.17³ | 10.22 ± 0.05³ | 10.37 ± 0.14³ | 10.28 ± 0.11³ | 10.46 ± 0.34³ |
|             | 150        | 10.45 ± 0.16³ | 10.26 ± 0.07³ | 10.06 ± 0.28³ | 10.42 ± 0.14³ | 10.66 ± 0.08³ | 10.34 ± 0.22³ | 12.28 ± 0.24³ |
|             | 180        | 9.88 ± 0.10³ | 9.11 ± 0.31³ | 11.129 ± 0.10³ | 10.73 ± 0.02³ | 9.65 ± 0.10³ | 10.76 ± 0.05³ | 10.83 ± 0.08³ |

¹Mean ± standard deviation obtained in two experiments, one of two experiments in duplicated (n = 3). Different capital letters indicate significant differences (p < 0.05) among each time for treatments and different small letters indicate significant differences (p < 0.05) among each treatment for times.

²R-con means control group that was treated using only a roaster machine.

³UA means a group that was treated by UV-A alone.

⁴TUA means a group that was treated by UV-C and TiO₂.

⁵UC means a group that was treated by UV-C alone.

⁶TUC means a group that was treated by UV-C and TiO₂.

⁷UAC means a group that was treated by UV-A and UV-C simultaneously.

⁸TUAC means a group that was simultaneously treated by UV-A, UV-C, and TiO₂.
a*, and b* values of untreated BPP were 53.55 ± 0.36, 2.16 ± 0.05, and 10.84 ± 0.11, respectively. In the case of R-con, L*, a*, and b* values both significantly (p < 0.05) decreased and increased during treatment. The L*, a*, and b* values of BPP increased or decreased by 3.49, 0.22, and 0.96, respectively. However, because there is no significant (p > 0.05) trend depending on treatment time or treatment group, the change of color values by R-con is considered to be within the standard deviation between the samples.

When UA treatment was performed for 180 min, the L* value and the b* value decreased by 4.83 and 1.73, respectively, which were significantly (p < 0.05) different from those of R-con. This results indicated that the brightness of BPP is decreased, and the degree of blue of the pepper powder is increased by treatment. After TUC, the BPP was bluer than the R-con pepper powder at 90 and 180 min. The blue color of BPP treated by TUAC increased at 30 min but decreased again after 60 min. During the treatment, the blue color of BPP seemed to be increased by TUC and TUAC. However, since the value increased and decreased irregularly, it remains unclear whether the color of BPP is affected by TUC and TUAC. Therefore, we concluded that all treatments except UA did not affect the color of BPP. The combined treatment of UV-A, UV-C, and TiO2 coating was considered to be suitable for BPP as a treatment to inactivate food poisoning bacteria.

Ishibashi proved that -O2 is generated in air and TiO2 interface by UV light using chemiluminescence method with high sensitivity (Ishibashi et al., 2000). This study tried to inactivate pathogens by directly contacting the black pepper powder inoculated pathogens with TiO2 coated on the roaster machine during UV irradiation. The treatments were used alone or combined to confirm increasing inactivation effects. Combined treatment of UV-A and UV-C was effective for inactivating S. Typhimurium. The TiO2 coating increased the inactivation effect of UV-A and UV-C against S. Typhimurium and E. coli O157:H7. There was no significant (p > 0.05) difference between productions of the injured S. Typhimurium and E. coli O157:H7 depending on the treatments. UV-A, UV-C and TiO2 coating do not affect production of the injured cell on BPP. The moisture content of BPP was decreased more by UV-A than by UV-C. UV-A treatment alone decreased the brightness and increased the degree of blue on BPP for 180 min, but the other treatments did not affect the color of the BPP. Therefore, the combined treatment of UV-A, UV-C, and TiO2 coating maintains the quality of BPP and can be used effectively to sterilize BPP without heating.

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