Effects of UV Irradiation on Selected Pathogens in Peptone Water and on Stainless Steel and Chicken Meat

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ABSTRACT

Effects of intensity and processing time of 254 nm UV irradiation on *Listeria monocytogenes*, *Escherichia coli* O157:H7, and *Salmonella Typhimurium* were investigated. Intensities measured at 5.08, 10.1, 15.2, and 20.3 cm from the light source were 1,000, 500, 250, and 150 μW/cm², respectively. Intensities of 250 or 500 μW/cm² reduced all suspended pathogen cells in peptone water about 5 log cycles after 2 min and completely inactivated *L. monocytogenes* and *E. coli* O157:H7 after 3 min by reductions of 8.39 and 8.64 log cycles, respectively. Intensities of 250 or 500 μW/cm² also reduced (P # 0.05) the tested pathogens inoculated on stainless steel (SS) chips, and *E. coli* O157:H7 was completely destroyed at 500 μW/cm² for 3 min. After UV treatment for 3 min at 500 μW/cm², all selected pathogens on chicken meat with or without skin showed reduction ranges from 0.36 to 1.28 log cycles. Results demonstrated that UV irradiation could effectively decrease pathogens in peptone water and on SS but that it was less effective on chicken meat.

UV irradiation has been used in the dairy industry and in meat, vegetable, and fish processing plants to reduce surface microbiological counts (11, 16). UV irradiation is a potential alternative to chlorine and is less expensive than conventional chlorination (3, 4). Kaess and Weidemann (11) reported that continuous UV irradiation of psychrophilic microorganisms growing on chilled beef slices resulted in an extension of the lag phase of *Pseudomonas* sp. and of the molds *Thamnidium* sp. and *Penicillus* sp. Immediate exposure to UV light of five bacterial cultures (*Staphylococcus epidermidis*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, and *Serratia marcescens*) that were applied on tryptic soy agar resulted in a 6- to 7-log decrease in numbers of viable bacteria (2). UV irradiation is also effective in killing microorganisms that contaminate the surfaces of a variety of packaging materials (e.g., polyethylene) for aseptic packaging (9, 12).

The number of foodborne illnesses associated with bacterial enteropathogens is still a major concern to the food industry, despite significant advances made toward a better understanding of bacterial transmission and pathogenicity in foods, use of good manufacturing practices, and other quality assurance plans in the food industry (13). The effectiveness of UV irradiation on pathogenic microorganisms should be of value to the application of UV irradiation in hazard analysis critical control point; however, no studies have been conducted to compare the effectiveness of UV irradiation to selected pathogens in water and on stainless steel (SS) and chicken meat. In this study, the effectiveness of UV light in inhibiting pathogenic bacteria (*Listeria monocytogenes*, *E. coli* O157:H7, and *Salmonella Typhimurium*) in peptone water and on SS and cooked chicken meat with or without skin was investigated.

MATERIALS AND METHODS

UV equipment. A UV bench lamp with a maximum intensity of 1,000 μW/cm² at 254 nm was used. This lamp is composed of a chamber (26 by 22 by 18 cm) with a lamp holder on the top (Model UVG-54, Ultra-Violet Products Inc., Upland, Calif.). A sample holding tray was wrapped with aluminum foil to give an effective increase in intensity and was mounted inside the chamber. Intensities of UV light were measured at 5.08, 10.1, 15.2, and 20.3 cm (Fig. 1) from the light source using a UVX digital UV radiometer (Ultra-Violet). After 3 min of warming up, the intensity determined with the UV radiometer was not changed. The UV dose was determined by multiplying the exposure time (minutes) by the applied intensity and was expressed as microwatts per minute per square centimeter (Tables 1 through 3).

Culture preparation. *L. monocytogenes* (ATCC 19111), *E. coli* O157:H7 (ATCC 43893), and *Salmonella Typhimurium* (ATCC 14028) were obtained and maintained through monthly transfer on tryptic soy agar (Becton Dickinson, Sparks, Md.) slants and stored at 4±8°C. All cultures were grown in tryptic soy broth (Becton Dickinson) for approximately 24 h at 35±8°C to a total plate count of approximately 10⁹ CFU/ml. Cells were harvested by centrifugation (Sorval RC-5B Plus centrifuge, Sorval Instruments, DuPont, Newtown, Conn.) at 17,000 × g for 5 min at 4°C and resuspended in 10 ml of 0.1% peptone water after washing to remove residual growth media. Populations were approximately 10⁹ CFU/ml.

Effect of UV light on pathogens in peptone water. Ten milliliters of diluted harvested cells was added to sterile 90 ml of 0.1% peptone water. For each treatment, 10 ml of the diluted culture suspension was transferred to a sterile petri dish (100 by 15 mm), and then the petri dish (without lid) was treated separately with UV light for 1, 2, and 3 min at intensities of 250 and

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TABLE 1. Effects of UV light at 250 and 500 μW/cm² on selected pathogens suspended in peptone water

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Dose (μW/min/cm²): 0</th>
<th>250 (1 min)</th>
<th>500 (2 min)</th>
<th>750 (3 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250 μW/cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>250 (1 min)</td>
<td>500 (2 min)</td>
<td>750 (3 min)</td>
</tr>
<tr>
<td>Listeria monocytogenes</td>
<td>8.39 A</td>
<td>6.10 B</td>
<td>2.45 C</td>
<td>ND</td>
</tr>
<tr>
<td>Salmonella Typhimurium</td>
<td>8.94 A</td>
<td>6.07 B</td>
<td>3.58 C</td>
<td>2.28 C</td>
</tr>
<tr>
<td>Escherichia coli O157:H7</td>
<td>8.64 A</td>
<td>5.42 B</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Log CFU/ml

a Means of three replications within a row in a dosage group not followed by same letter differ (P ≤ 0.05).

b ND, none detected at 10⁻¹ dilution.

Intensities of UV light. Various intensities of UV light were measured for 1 min by controlling distances from the UV lamp. Intensities ranged from 150 to 1,000 μW/cm² (Fig. 1). Bank et al. (2) described the way in which the bactericidal efficacy of UV lamps was focused on the bulb, intensity, and time of exposure.

Effect of UV light on pathogens on SS chips. Polished SS chips (Type 304 with No. 4) were cut into pieces (2 by 2 cm²), soaked overnight in detergent (VioNex, VIONEX, Durango, Colo.), scrubbed thoroughly with a brush, rinsed three times in tap water and twice in distilled water, and autoclaved at 121°C for 15 min. Throughout the experiment, they were handled aseptically with sterile forceps. The sterile SS chips (2 by 2 cm²) were then dipped into 200 ml of each cultured broth of approximately 10⁶ CFU/ml for 10 min. Inoculated SS chips were aseptically dried for 30 min at room temperature (25°C). After drying, the inoculated SS chips were irradiated with UV light for 1, 2, and 3 min at intensities of 250 and 500 μW/cm². Surviving cells on the complete surface of a side on SS chips were swabbed with sterile cotton swab (1). Survival cells were enumerated as described above. The total number of cells on each SS chip was divided by the area (4 cm²) of an SS chip and then reported as log colony-forming units per square centimeter. Joseph et al. (10) used the swabbing method with sterile cotton swabs to remove Salmonella biofilm cells on SS coupons, and they described that the limit of detection by this method was 25 cells/cm².

Effect of UV light on selected pathogens on chicken meat. Chicken breast meat (5 by 5 by 1 cm³) with or without skin was autoclaved at 121°C for 15 min and aseptically cooled to room temperature (25°C). The sterile chicken meat with or without skin was then dipped into 200 ml of a cultured tryptic soy broth with approximately 10⁸ CFU/ml for 10 min. After draining for 5 min, the inoculated samples were treated with UV light for 1, 2, and 3 min at an intensity of 500 μW/cm². Cell numbers were enumerated as described above by swabbing a surface (2 by 2 cm²), with or without skin.

Statistical analyses. A completely randomized design with three replications was used for each study. Analysis of variance was performed using mean log microbial population data to determine differences between treatments and control. The General Linear Models of SAS software (15) was used to analyze all data, with treatment and control as the main effect. When differences among treatments existed (P ≤ 0.05), means were separated by Fisher’s protected least significant difference test (5).

RESULTS AND DISCUSSION

500 μW/cm², which were measured at 10.1 and 15.2 from the light source, respectively. After treatment, surviving pathogens were enumerated by serial dilution in peptone water and surface-inoculating tryptic soy agar (Becton Dickinson) plates. Plates were incubated at 37°C for 48 h for L. monocytogenes and for 24 h for E. coli O157:H7 and Salmonella Typhimurium.

Effect of UV light on pathogens on SS chips. Polished SS chips (Type 304 with No. 4) were cut into pieces (2 by 2 cm²), soaked overnight in detergent (VioNex, VIONEX, Durango, Colo.), scrubbed thoroughly with a brush, rinsed three times in tap water and twice in distilled water, and autoclaved at 121°C for 15 min. Throughout the experiment, they were handled aseptically with sterile forceps. The sterile SS chips (2 by 2 cm²) were then dipped into 200 ml of each cultured broth of approximately 10⁶ CFU/ml for 10 min. Inoculated SS chips were aseptically dried for 30 min at room temperature (25°C). After drying, the inoculated SS chips were irradiated with UV light for 1, 2, and 3 min at intensities of 250 and 500 μW/cm². Surviving cells on the complete surface of a side on SS chips were swabbed with sterile cotton swab (1). Survival cells were enumerated as described above. The total number of cells on each SS chip was divided by the area (4 cm²) of an SS chip and then reported as log colony-forming units per square centimeter. Joseph et al. (10) used the swabbing method with sterile cotton swabs to remove Salmonella biofilm cells on SS coupons, and they described that the limit of detection by this method was 25 cells/cm².

Effect of UV light on selected pathogens on chicken meat. Chicken breast meat (5 by 5 by 1 cm³) with or without skin was autoclaved at 121°C for 15 min and aseptically cooled to room temperature (25°C). The sterile chicken meat with or without skin was then dipped into 200 ml of a cultured tryptic soy broth with approximately 10⁸ CFU/ml for each pathogen for 10 min. After
risk of less than 5 log cycles of E. coli with UV treatment in apple cider occurred less than 0.2% of the time. 

**Effect of UV light on SS chips and chicken meat.**

Table 2 shows the effect of UV irradiation on inoculated cells of L. monocytogenes, Salmonella Typhimurium, and E. coli O157:H7 on SS. At both intensities, the inactivation of all inoculated cells was significant ($P > 0.05$) after 3 min. E. coli O157:H7 on SS chips was totally destroyed (a 6.19-log reduction) when exposed at 500 μW/cm² for 3 min, while L. monocytogenes and Salmonella Typhimurium on SS chips were more resistant to UV light (Table 2). Frank and Koffi (7) and Oh and Marshall (14) demonstrated that the resistance of L. monocytogenes to various sanitizers and heat was due to surface-bound lipopolysaccharide-like substances produced by L. monocytogenes. All inoculated pathogens on chicken meat with or without skin treated with 500 μW/cm² for 3 min showed less than a 1.3-log reduction (Table 3). This result supports the finding of Wallner-Pendleton et al. (18) that only a 1/2-log (66%) reduction in Salmonella Typhimurium was observed in UV-treated chicken halves (doses ranged from 82,560 to 86,400 μW/s/cm² at a wavelength of 253.7 nm) compared to untreated halves. UV light is more effective at killing bacteria, including Salmonella, on smooth surfaces (12). Chicken carcasses do not have smooth surfaces, and the skin is lined irregularly with numerous feather follicles. Bacteria may enter pores left by feather follicles, thus becoming inaccessible to UV light (18). Stermer et al. (16) also reported UV light with principal energy at a wavelength of 253.7 nm, and it was effective in destroying about 2 log cycles of bacteria on the surface of fresh beef round steak. They also found that UV light was less effective on the rough surfaces of fresh meat such as round steak, because bacteria were partly shielded from the radiation. Huang and Toledo (9) reported that UV irradiation (300 μW/cm² at a wavelength of 254 nm) on the rough surfaces of mackerel was effective in reducing 2 to 3 log cycles of the surface microbial count and prolonging a longer shelf life (7 days) than conventional ice-packed untreated controls. L. monocytogenes, Salmonella Typhimurium, and E. coli O157:H7 on chicken meat skin treated with 500 μW/cm² for 3 min showed 0.48-, 1.02-, and 1.28-log reductions while showing 0.46-, 0.36-, and 0.93-log reductions without skin (Table 3). E. coli O157:H7 on chicken meat with or without skin showed 1.28- and 0.93-log reductions, respectively, while L. monocytogenes on chicken meat without skin did not show a significant reduction ($P > 0.05$) (Table 3). These results indicate that L. monocytogenes on chicken meat had the same resistance with SS chips.

In summary, UV irradiation was effective in reducing the number of pathogens inoculated in peptone water and on the surface of SS. There was little effect of UV irradiation on chicken meat surfaces with or without skin.

**REFERENCES**


**TABLE 2. Effects of UV light at 250 and 500 μW/cm² on selected pathogens inoculated on SS chips**

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Dose (μW/min/cm²):</th>
<th>250 μW/cm²</th>
<th>500 μW/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>250 (1 min)</td>
</tr>
<tr>
<td><strong>Listeria monocytogenes</strong></td>
<td>5.49 A</td>
<td>3.06 B</td>
<td>1.83 C</td>
</tr>
<tr>
<td><strong>Salmonella Typhimurium</strong></td>
<td>5.49 A</td>
<td>2.3 B</td>
<td>1.7 C</td>
</tr>
<tr>
<td><strong>Escherichia coli O157:H7</strong></td>
<td>6.19 A</td>
<td>1.81 B</td>
<td>1.51 C</td>
</tr>
</tbody>
</table>

*Means of three replications within a row in a dosage group not followed by same letter differ ($P \leq 0.05$).

**TABLE 3. Effects of UV light at 500 μW/cm² on selected pathogens inoculated on chicken meat with or without skin**

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Dose (μW/min/cm²):</th>
<th>With skin</th>
<th>Without skin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>500 (1 min)</td>
</tr>
<tr>
<td><strong>Listeria monocytogenes</strong></td>
<td>5.84 A</td>
<td>5.59 B</td>
<td>5.49 C</td>
</tr>
<tr>
<td><strong>Salmonella Typhimurium</strong></td>
<td>5.62 A</td>
<td>5.19 B</td>
<td>4.87 C</td>
</tr>
<tr>
<td><strong>Escherichia coli O157:H7</strong></td>
<td>6.25 A</td>
<td>6.08 A</td>
<td>5.49 B</td>
</tr>
</tbody>
</table>

*Means of three replications within a row in a dosage group not followed by same letter differ ($P \leq 0.05$).


