Efficacy of UV Light Treatment for the Microbiological Decontamination of Chicken, Associated Packaging, and Contact Surfaces

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ABSTRACT

UV light was investigated for the decontamination of raw chicken, associated packaging, and contact surfaces. The UV susceptibilities of a number of *Campylobacter* isolates (seven *Campylobacter jejuni* isolates and three *Campylobacter coli* isolates), *Escherichia coli* ATCC 25922, and *Salmonella enterica* serovar Enteritidis ATCC 10376 in liquid media were also investigated. From an initial level of 7 log CFU/ml, no viable *Campylobacter* cells were detected following exposure to the most intense UV dose (0.192 J/cm^2) in liquid media (skim milk subjected to ultrahigh-temperature treatment and diluted 1:4 with maximum recovery diluent). Maximum reductions of 4.8 and 6.2 log CFU/ml were achieved for *E. coli* and serovar Enteritidis, respectively, in liquid media. Considerable differences in susceptibilities were found between the *Campylobacter* isolates examined, with variations of up to 4 log CFU/ml being observed. UV treatment of raw chicken fillet (0.192 J/cm^2) reduced *C. jejuni, E. coli,* serovar Enteritidis, total viable counts, and *Enterobacteriaceae* by 0.76, 0.98, 1.34, 1.76, and 1.29 log CFU/g, respectively. Following UV treatment of packaging and surface materials, reductions of up to 3.97, 4.50, and 4.20 log CFU/cm^2 were obtained for *C. jejuni, E. coli,* and serovar Enteritidis, respectively ($P < 0.05$). Overall, the color of UV-treated chicken was not significantly affected ($P \geq 0.05$). The findings of this study indicate that *Campylobacter* is susceptible to UV technology and that differences in sensitivities exist between investigated isolates. Overall, UV could be used for improving the microbiological quality of raw chicken and for decontaminating associated packaging and surface materials.

The external and internal surfaces of packaging for raw meats, including poultry, have frequently been shown to be contaminated with pathogens such as *Campylobacter, Salmonella,* and *Escherichia coli (9, 23)*. These bacteria are recognized as the most frequent causes of bacterial foodborne gastroenteritis worldwide *(7, 19, 31)*. Poultry products are considered an important infectious route for humans *(25)*. A recent study by the European Food Safety Authority reported average *Campylobacter* and *Salmonella* contamination levels on broiler carcasses of 75.8 and 15.7%, respectively, with some member states reporting up to 100 and 85.6% detection of *Campylobacter* and *Salmonella,* respectively, on carcasses *(6)*. Contamination of external packaging, in particular, poses a potential opportunity for cross-contamination of surfaces, other foods (including ready-to-eat foods), and people in retail premises and consumers' homes *(1)*. Quantitative risk assessment studies for *Campylobacter* in chicken demonstrate that the most effective intervention measures aim at reducing the *Campylobacter* level on carcasses and products rather than reducing the prevalence of positive flocks *(21)*. Sequential reduction in the numbers of *Campylobacter* coming through the food chain at pertinent stages can result

in an overall decrease in human foodborne illness associated with that organism. UV light processing involves the use of radiation from the UV region (100 to 400 nm) of the electromagnetic spectrum for the purposes of disinfecting surfaces on packaging or in food processing, and its effectiveness has been previously demonstrated in various studies to date *(3, 5, 12, 26)*. The mode of action of UV has been attributed to photochemical transformation of pyrimidine bases that produce links between successive pyrimidines on a DNA strand to form dimers *(18)*. The resulting effect is that DNA transcription and replication are blocked, compromising cellular functions and eventually leading to cell death *(8)*. There is a growing interest in using UV light for food preservation, particularly as UV disinfection does not require chemicals or heat and is relatively inexpensive *(4, 8)*. UV has been approved by the U.S. Food and Drug Administration as a means for controlling surface microorganisms on food products *(27)*. In the European Union, there is currently no legislation prohibiting the use of UV for treating food products, and its approval for use is dependent on relevant national regulations within individual member states. General consumer acceptability of irradiated foods is low but could be improved by education, as the lack of information and understanding has been the main obstacle for dissemination of this technology *(14)*. The potential of UV light for

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the decontamination of chicken has previously been investigated, and studies have concluded that it could be useful for this application. Furthermore, it is claimed that following UV treatment the appearance and sensory quality of fresh chicken are not impaired (12, 28). A limited number of studies have investigated UV light as a decontamination technology for raw poultry. Isohanni and Lyhs (12) applied UV light to broiler breast fillets and skin and achieved reductions of 0.7 and 0.8 log CFU/ml, respectively, for *Campylobacter jejuni*. Chun et al. (4) obtained maximum reductions of 1.26- and 1.19-log CFU/g for *C. jejuni* and *Salmonella* Typhimurium, respectively, following UV treatment of chicken breasts. Additionally, data pertaining to the susceptibility of *Campylobacter* to UV technology are scarce, and to our knowledge, it has not been established to date if variations between isolates or species exist. Therefore, an examination of the effectiveness of UV treatment on a range of *Campylobacter* isolates would be a useful undertaking at this stage. While the application of the UV technology as a surface decontamination method has previously been investigated (8, 15, 18), information relating to its application for sanitizing poultry-associated packaging materials and surfaces is scant.

The objectives of the current study were twofold: (i) to investigate the susceptibility to UV light in liquid media of a collection of *Campylobacter* isolates from various sources and also of *E. coli* (ATCC 25922) and *Salmonella enterica* serovar Enteritidis (ATCC 13076); and (ii) to assess the potential of UV treatment to decontaminate raw poultry and to sanitize associated food contact surfaces and packaging materials.

MATERIALS AND METHODS

Microorganisms and culture preparation. A total of 10 *Campylobacter* strains (7 *C. jejuni* strains and 3 *C. coli* strains) were used in the susceptibility studies. The *C. coli* strains were 1140 DF, 1662 DF, and 2124 GF, while strains 323 BC, 1135 DF, 1136 DF, 1146 DF, 1147 DF, 1354 DF, and NCTC 11168 were *C. jejuni*. All strains were isolated from retail chicken except 323 BC and the typed *C. jejuni* strain NCTC 11168, both of which are of clinical origin. All *Campylobacter* chicken isolates were recovered and confirmed by methods described previously (29, 30). *E. coli* (ATCC 25922) and *Salmonella* Enteritidis (ATCC 13076) strains were obtained from the American Type Culture Collection. Stock cultures of *Campylobacter* were maintained in defibrinated horse blood (Oxoid, Basingstoke, UK), while *E. coli* and *Salmonella* Enteritidis were stored in nutrient broth (Oxoid) containing 20% glycerol at −80°C. *Campylobacter* strains were resuscitated by inoculating a loopful of the frozen stock into Mueller-Hinton broth (Oxoid) containing *Campylobacter* growth supplement (Oxoid) and incubating microaerobically for 48 h at 42°C. A microaerobic atmosphere of 5% O_2 and 15% CO_2 was obtained by using a GENbox jar and GENbox microaer gas generators (bioMérieux, Marcy l'Etoile, France). Stocks of *E. coli* and *Salmonella* Enteritidis were resuscitated by inoculating a loopful of defrosted stock into tryptone soy broth (TSB; Oxoid) and incubating for 24 h at 37°C. The enriched *Campylobacter* cultures were then streaked onto both Columbia blood agar (Oxoid) and modified charcoal cefoperazone deoxycholate agar (mCCDA; Oxoid) and incubated microaerobically for a further 48 h at 42°C. *E. coli* and *Salmonella* Enteritidis were streaked onto tryptone soy agar (TSA; Oxoid) and incubated for 24 h at 37°C.
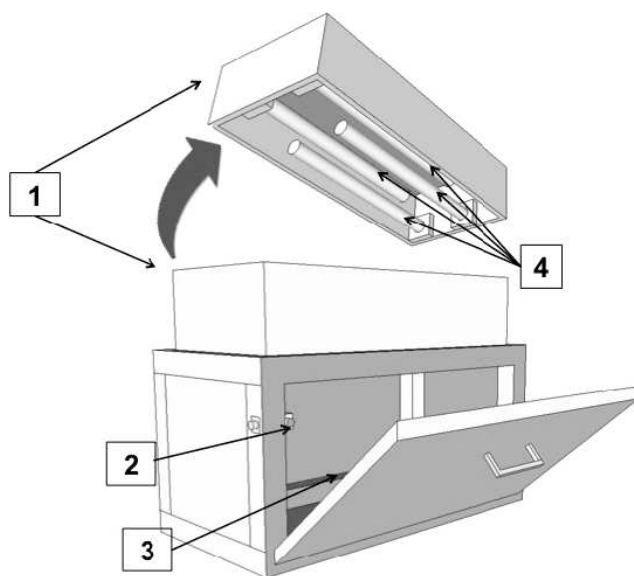

FIGURE 1. *Layout of UV treatment unit. 1, housing for UV lights; 2, safety interlock; 3, treatment chamber with dimensions (length, width, and height) of 790 by 390 by 345 mm; 4, UV lights (95 W) 500 mm in length.*

Preparation of bacterial suspensions for UV susceptibility studies. *Campylobacter* suspensions were prepared by transferring a single colony off a 48-h blood agar plate to 20 ml of Mueller-Hinton broth containing *Campylobacter* growth supplements and incubating for 24 h. The 24-h suspensions were centrifuged for 10 min at 30,000 × g, and the resulting pellet was washed and recentrifuged twice in maximum recovery diluent (MRD; Oxoid) before final resuspension in 20 ml of treatment medium (skim ultrahigh-temperature–treated [UHT] milk diluted with MRD in a 1:4 ratio). This resulted in a liquid cell suspension of approximately 10^7 CFU/ml. *E. coli* and *Salmonella* Enteritidis suspensions were prepared by transferring a single colony from a TSA plate to 20 ml of TSB and incubating at 37°C for 24 h. The *E. coli* and *Salmonella* Enteritidis suspensions were then centrifuged, washed, and resuspended in the treatment medium as described previously. This resulted in cell suspensions containing approximately 10^8 CFU/ml, which were then exposed to various UV light treatments. The liquid suspension of skim UHT milk and MRD was used to reduce the penetration of UV light in order to allow differences in susceptibilities between the isolates examined to be detected at the various dosages applied.

UV equipment. The UV unit was a custom-made unit with internal dimensions (length by width by height) of 790 by 390 by 345 mm and consisting of four 95-W bulbs (Baro Applied Technology Limited, Manchester, UK) 500 mm in length (Fig. 1). An initial characterization of the UV chamber was performed by using a UV-VIS Radiometer (model no. RM12, Dr Gröbel UV-Electronik, GmbH, Ettlington, Germany) fitted with an RM sensor UV-C (part no. 811010, Dr Gröbel UV-Electronik) to establish the UV irradiance at a total of 27 carefully selected locations within the chamber (three times each dimension, i.e., width, depth, and height measurements). The location that consistently delivered the highest irradiance was selected for further studies. The UV dose (*D*) was calculated by using the following equation:

$$D = I_{254} \times t$$

where *D* is the dose (in joules per square meter), I_{254} is the dosage rate (D_r, in watts per square meter), and *t* is the retention time (in

TABLE 1. *UV-C irradiance and calculated dosages at selected distances from the light source*

Distance from UV lamps (cm)	UV-C irradiance (J/cm^2)	UV-C dose per treatment (J/cm^2)				
		2 s	4 s	8 s	16 s	32 s
6.5	0.006	0.012	0.024	0.048	0.096	0.192
17	0.005	0.010	0.020	0.040	0.080	0.160
28.5	0.004	0.008	0.016	0.032	0.064	0.128

seconds) *(8)*. The UV dosages (in joules per square centimeter) were varied by altering the distance of the sample (6.5, 17, and 28.5 cm) from the light source and by changing the treatment time (2 to 32 s) (Table 1).

UV treatment of bacteria in liquid matrices. All 10 *Campylobacter* isolates were initially assessed for susceptibility to UV in a liquid matrix (1:4 UHT diluted with MRD), and the least susceptible isolate (1147 DF) was then selected for further study. *E. coli* and *Salmonella* Enteritidis were also subjected to equivalent UV treatments. *C. jejuni, C. coli, E. coli,* and *Salmonella* Enteritidis pure cultures were prepared as described previously. Samples (3 ml) were then placed in petri dishes (50-mm diameter) resulting in a liquid depth of 1.5 mm (Sterilin Limited, Caerphilly, UK) and exposed to UV doses in the range of 0.008 to 0.192 J/cm^2 (Table 1). Sample temperatures were measured pre- and posttreatment by using a K-type thermocouple attached to a Grant Data Logger (Squirrel 2040, Grant Instruments, Cambridge, UK) to ensure the maximum temperature reached was nonlethal to the bacteria under the treatment times investigated (i.e., $\leq 50°C$).

UV treatment of bacteria on raw chicken. To investigate the effectiveness of UV for the decontamination of raw poultry, skinless chicken breast meat and skin were inoculated with bacteria and treated with UV. Pieces of raw skinless breast meat and skin were dipped in the bacterial suspensions for 20 s. The inoculated skinless breast meat and skin sections were then placed in sterile petri dishes and stored at ambient temperature for 30 min to allow bacterial attachment before samples were exposed to UV doses of 0.048, 0.096, and 0.192 J/cm^2. Skin samples were treated on both sides, which involved treating the upper surface and then aseptically inverting and transferring the sample to a sterile petri dish for further UV treatment. Sample temperatures were measured posttreatment with an infrared thermometer (RS 1327, RS Components Ltd., Corby, Northamptonshire, UK) to ensure the maximum temperature did not exceed 50°C and was therefore nonlethal to the bacteria under the treatment times investigated *(11, 13, 16)*.

UV treatment of bacteria on food contact surfaces and packaging materials. A selection of food contact surfaces and packaging materials commonly used in poultry processing were examined in this study (Table 2). Materials were cut into sections (5 by 5 cm), cleaned thoroughly with 70% ethanol, and kept in sterile 90-mm-diameter petri dishes (Sarstedt, Wexford, Ireland) until required. Prior to inactivation studies, a range of UV treatments were investigated on all materials to determine treatment parameters, which resulted in a final temperature of $\leq 50°C$. UV doses in the range of 0.010 to 0.192 J/cm^2 were chosen for subsequent microbiological inactivation studies, as shown in Table 1. Bacterial cultures of *C. jejuni* (1147 DF), *E. coli,* and *Salmonella* Enteritidis were prepared in MRD as described previously and transferred to the upper surfaces of all materials under investigation by applying an aerosolized inoculum with a spray bottle. Before inoculation, the spray bottle was cleaned with 1% Trigene (Medichem International Ltd., Queenborough, Kent, UK) followed by sterile MRD to remove any remains of the disinfectant. The spray bottle was then primed with the bacterial culture before spraying onto food contact surfaces and packaging materials. The spray nozzle was held at a distance of approximately 50 cm from the surface of the material, which was held at a 45° angle to the nozzle with a sterile forceps. Each piece received three sprays, resulting in an inoculum of between 3 and 4 log CFU of *C. jejuni, Salmonella* Enteritidis, and *E. coli* per cm^2. After inoculation, the underside of the material was carefully wiped with 70% ethanol solution to remove any inoculum that may have been inadvertently transferred.

Microbiological analysis. Following treatment of liquid samples, the content of the petri dish was transferred to a sterile container. A 10-fold dilution series was prepared in MRD, and 0.1 ml of each dilution was spread plated in duplicate onto mCCDA for *Campylobacter* and TSA for both *E. coli* and *Salmonella* Enteritidis. The mCCDA and TSA plates were incubated at 37°C for 48 and 24 h, respectively. Following treatment of raw skinless breast meat, 2 g was aseptically removed from the surface and stomached in 18 ml of MRD. For skin samples, 2 g of the sample was weighed and stomached in 18 ml of MRD. Dilutions, plating, and incubation were carried out as previously described. Mean counts for each treatment were calculated and converted to log CFU values with results for surviving numbers of microorganisms in MRD expressed in CFU

TABLE 2. *Food contact surfaces and packaging materials evaluated in the current study*

	Material (abbreviation)	Application
Food contact surfaces	Stainless steel (SS)	Common surface in poultry processing facilities
	Polyethylene cutting board (PCB)	Food preparation surface
Packaging materials	Black polypropylene tray (BPP)	Poultry portions
	White polypropylene tray (WPP)	Poultry portions
	Blue polystyrene tray (PS)	Whole birds
	Aluminum tray (AL)	Prepared poultry products
	Polyolefin (PO)	Covering of whole birds on trays
	Polyethylene-polypropylene (PET-PP)	Sealing of polypropylene trays
	Polyvinyl chloride (PVC)	Covering of whole birds on trays

per milliliter. Microbial counts on packaging and surface materials were expressed in CFU per square centimeter, and microbial counts on raw chicken were expressed in CFU per gram.

Instrumental color analysis. To determine whether treatment with UV light had any negative effects on the visual appearance of skinless breast meat, instrumental color analysis was performed. The Hunter L (lightness), a (redness-greenness), and b (yellowness-blueness) values were measured with a Chroma Meter CR-300 (Konica Minolta Co. Ltd., Ramsey, NJ), which had been calibrated with the standard white tile prior to use. As the color of untreated raw skinless breast meat was found to differ considerably between samples, the color of each sample was measured before and after treatment. Prior to treatment, color measurements were taken from three random locations and averaged to get an overall mean measurement for each of three replicate samples. Following UV treatment, triplicate measurements were taken randomly and analyzed as previously described. The changes in color (ΔL, Δa, and Δb) were calculated by subtracting the values obtained before treatment from the values obtained after treatment.

Statistical analysis. Statistical analysis was carried out by using a general linear model in SAS version 9.1 (SAS Institute, Cary, NC). Each experiment was carried out in triplicate ($n = 3$).

RESULTS

UV treatment of bacteria in a liquid matrix. Following the most intense UV dose (0.192 J/cm^2), no viable *Campylobacter* cells were detected for any of the 10 isolates under investigation (Fig. 2). Interestingly, reductions in populations varied significantly, by up to 4 log cycles following exposure to UV doses of 0.032, 0.040, and 0.048 J/cm^2 ($P < 0.05$). For example, Figure 2 shows that following exposure to 0.032 J/cm^2, 1354 DF was the most susceptible while 1147 DF was the least susceptible, with respective reductions of 6.5 and 3.5 log CFU/ml observed. As 1147 DF was consistently the least susceptible isolate, it was selected for further studies with raw poultry, associated packaging materials, and contact surfaces. Reductions of up to 4.8 and 6.2 log CFU/ml were obtained for *E. coli* and *Salmonella* Enteritidis, respectively, under the most intense UV treatment of 0.192 J/cm^2.

UV treatment of raw poultry. Following UV treatment of inoculated raw poultry of up to 0.192 J/cm^2, significant maximum reductions of 0.76, 0.98, 1.34, 1.76, and 1.29 log CFU/g were achieved for *C. jejuni*, *E. coli*, *Salmonella* Enteritidis, total viable counts (TVC), and *Enterobacteriaceae*, respectively, on skinless chicken fillet ($P < 0.05$) (Table 3). There were no significant differences in the reductions obtained within the various UV treatments examined ($P \geq 0.05$).

Significant reductions of 0.58, 0.77, 1.01, and 0.30 log CFU/g were observed for *C. jejuni*, *E. coli*, *Salmonella* Enteritidis, and *Enterobacteriaceae*, respectively, on chicken skin after UV treatments of up to 0.192 J/cm^2 ($P < 0.05$). As before, increasing the UV dose from 0.048 to 0.192 J/cm^2 did not significantly reduce microbial loads. In contrast to skinless chicken fillet, no significant reductions were observed for TVC on skin after any of the UV treatments ($P \geq 0.05$).
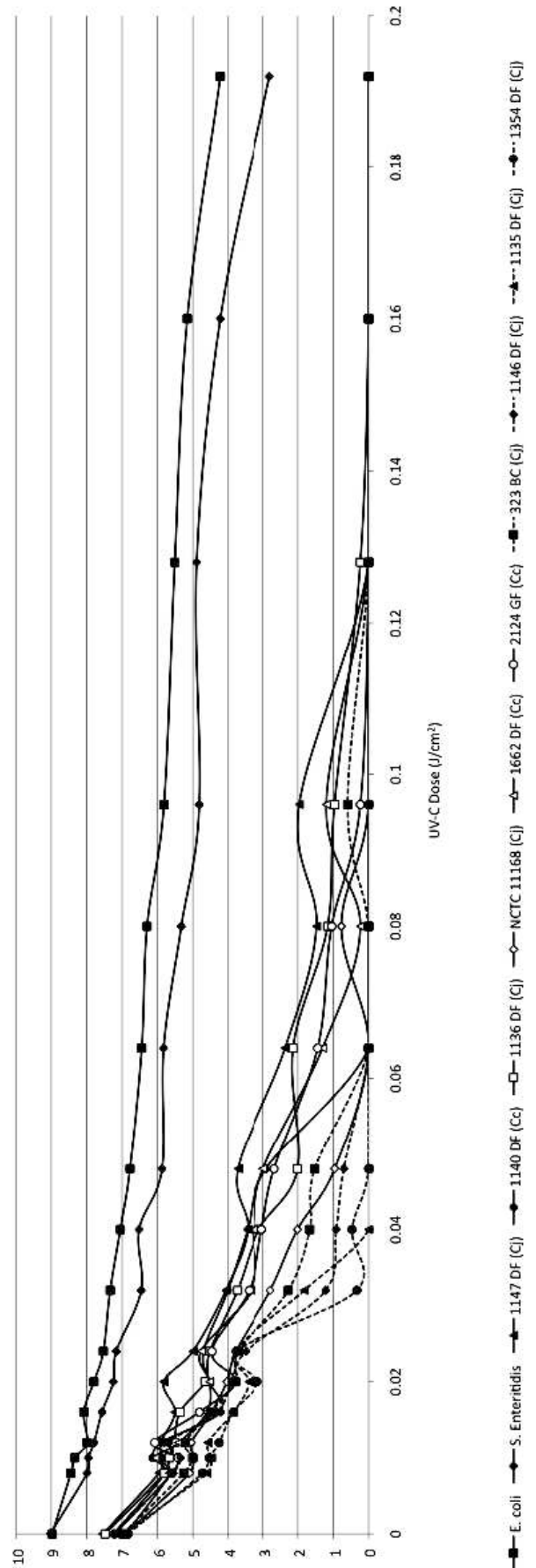

FIGURE 2. *UV inactivation of* C. jejuni *(Cj),* C. coli *(Cc),* E. coli *(Cc), E. coli, and serovar Enteritidis in liquid media (UV-C doses, 0 to 0.192 J/cm^2).*

TABLE 3. *Populations of C. jejuni, E. coli, Salmonella Enteritidis, TVC, and Enterobacteriaceae on skinless chicken breast and chicken skin after exposure to various doses of UV-C light[a]*

UV-C dose (J/cm²)	Skinless chicken breast					Chicken skin				
	C. jejuni	E. coli	Salmonella Enteritidis	TVC	EB	C. jejuni	E. coli	Salmonella Enteritidis	TVC	EB
0	4.04 ± 0.12 A	6.48 ± 0.12 A	6.35 ± 0.09 A	4.17 ± 0.49 A	3.59 ± 0.04 A	4.57 ± 0.19 A	7.08 ± 0.32 A	6.81 ± 0.06 A	4.78 ± 0.19 A	4.83 ± 0.09 A
0.048	3.41 ± 0.20 B	5.50 ± 0.13 B	5.26 ± 0.23 B	2.76 ± 0.12 B	2.39 ± 0.60 B	4.00 ± 0.03 B	6.41 ± 0.43 B	5.79 ± 0.24 B	4.64 ± 0.09 A	4.53 ± 0.30 B
0.096	3.38 ± 0.21 B	5.68 ± 0.21 B	5.28 ± 0.12 B	2.57 ± 0.04 B	2.61 ± 0.54 B	4.04 ± 0.13 B	6.31 ± 0.13 B	6.19 ± 0.10 B	4.67 ± 0.16 A	4.56 ± 0.20 B
0.192	3.28 ± 0.15 B	5.60 ± 0.14 B	5.01 ± 0.15 B	2.41 ± 0.04 B	2.30 ± 0.28 B	4.05 ± 0.08 B	6.41 ± 0.06 B	6.11 ± 0.07 B	4.73 ± 0.05 A	4.72 ± 0.55 A

[a] Values are means and standard deviations in log CFU per gram. Means within columns followed by the same letter are not significantly different ($P \geq 0.05$). EB, *Enterobacteriaceae*.

Color analysis of UV-treated raw poultry. Instrumental color analysis demonstrated negligible changes in the color of UV-treated chicken (Table 4). As shown in Table 4, UV treatments of up to 0.192 J/cm² did not affect the Hunter L or a values of raw chicken, although changes in some of the b values were significant.

UV treatment of bacteria on food contact surfaces and packaging materials. Significant reductions of *C. jejuni* (1147DF) were obtained for all materials under examination at each of the applied UV doses ($P < 0.05$) (Fig. 3A). In all cases, *Campylobacter* levels were reduced below the limit of detection (0.4 CFU/cm²), with the exception of low levels ($\leq$0.76 log CFU/cm²) recovered from polyethylene-polypropylene (PET-PP) following exposure to UV doses of $\leq$0.024 J/cm². Low levels (0.81 log CFU/cm²) of survivors were also detected on white polypropylene following the mildest UV treatment, i.e., 0.010 J/cm².

Significant reductions were achieved for *E. coli* on all materials following exposure to the various UV doses ($P < 0.05$) (Fig. 3B). There were no viable cells detected on any of the materials following exposure to UV doses exceeding 0.040 J/cm², with the exception of blue polystyrene (PS) and the PET-PP film. Increasing the UV treatment dose from 0.024 to 0.192 J/cm² significantly reduced *E. coli* on the PET-PP film from 2.11 to 0.90 log CFU/cm², respectively ($P < 0.05$). By contrast, increasing the UV dose beyond 0.012 J/cm² did not significantly reduce numbers of *E. coli* on blue PS, with residual levels remaining at approximately 2 log CFU/cm² ($P \geq 0.05$).

Significant reductions were achieved for *Salmonella* Enteritidis on all materials following treatment with various UV doses (Fig. 3C) ($P < 0.05$). Similar to *E. coli,* with the exception of PS or the PET-PP film, no viable cells were detected on any of the materials following UV exposure to $\geq$0.040 J/cm². The greatest levels of *Salmonella* Enteritidis were recovered from PS or the PET-PP film, with averages of 1.5 and 0.7 log CFU/cm², respectively, following exposure to UV treatment doses of up to 0.192 J/cm² (Fig. 3C).

DISCUSSION

UV treatment of bacteria in a liquid matrix. The current study showed that the UV susceptibilities of 10 *Campylobacter* isolates under investigation varied significantly ($P < 0.05$). Survival levels following similar treatments differed by up to 4 log CFU/ml. Although a number of previous studies have investigated the use of UV light against *Campylobacter,* to the authors' knowledge none have investigated differences in susceptibilities between isolates, as demonstrated in the current study (2, 3, 12, 20). In contrast to *E. coli* and *Salmonella* Enteritidis (two other gram-negative bacteria associated with poultry), *Campylobacter* was much more sensitive to UV treatment. This order of relative sensitivities is the same as that found in a recent study that investigated the effect of high-intensity 405-nm visible light on gram-negative bacteria. *C. jejuni* was most sensitive, followed by *E. coli,*

TABLE 4. *Color change of skinless breast meat following exposure to various doses of UV-C light*[a]

UV-C dose (J/cm^2)	ΔL	Δa	Δb
0.064	−0.69 ± 1.03 A	−0.03 ± 0.28 A	−0.39 ± 0.18 AB
0.080	−0.84 ± 1.29 A	0.03 ± 0.33 A	−0.14 ± 0.26 A
0.096	−0.15 ± 0.18 A	0.04 ± 0.25 A	−0.24 ± 0.10 AB
0.128	−0.83 ± 1.41 A	0.17 ± 0.30 A	−0.41 ± 0.24 AB
0.160	−0.42 ± 0.33 A	−0.20 ± 0.24 B	−0.23 ± 0.05 AB
0.192	−0.67 ± 1.27 A	0.12 ± 0.21 A	−0.32 ± 0.32 AB

[a] Within columns, means followed by the same letter are not significantly different ($P \geq 0.05$). ΔL, Δa, and Δb were calculated by subtracting the value of the untreated meat from that of the treated meat.

with *Salmonella* Enteritidis being the least sensitive *(20)*. However, the current study found *Salmonella* Enteritidis to be more sensitive to UV treatments than *E. coli,* and this could be due to strain-to-strain variation or differences in the wavelength ranges of the equipment used. UV doses of 50 J/m^2 (0.005 J/cm^2) and 140 J/m^2 (0.014 J/cm^2) have been reported to be adequate for a 4-log reduction of *E. coli* and *Salmonella* isolates, respectively, in drinking water *(8)*.
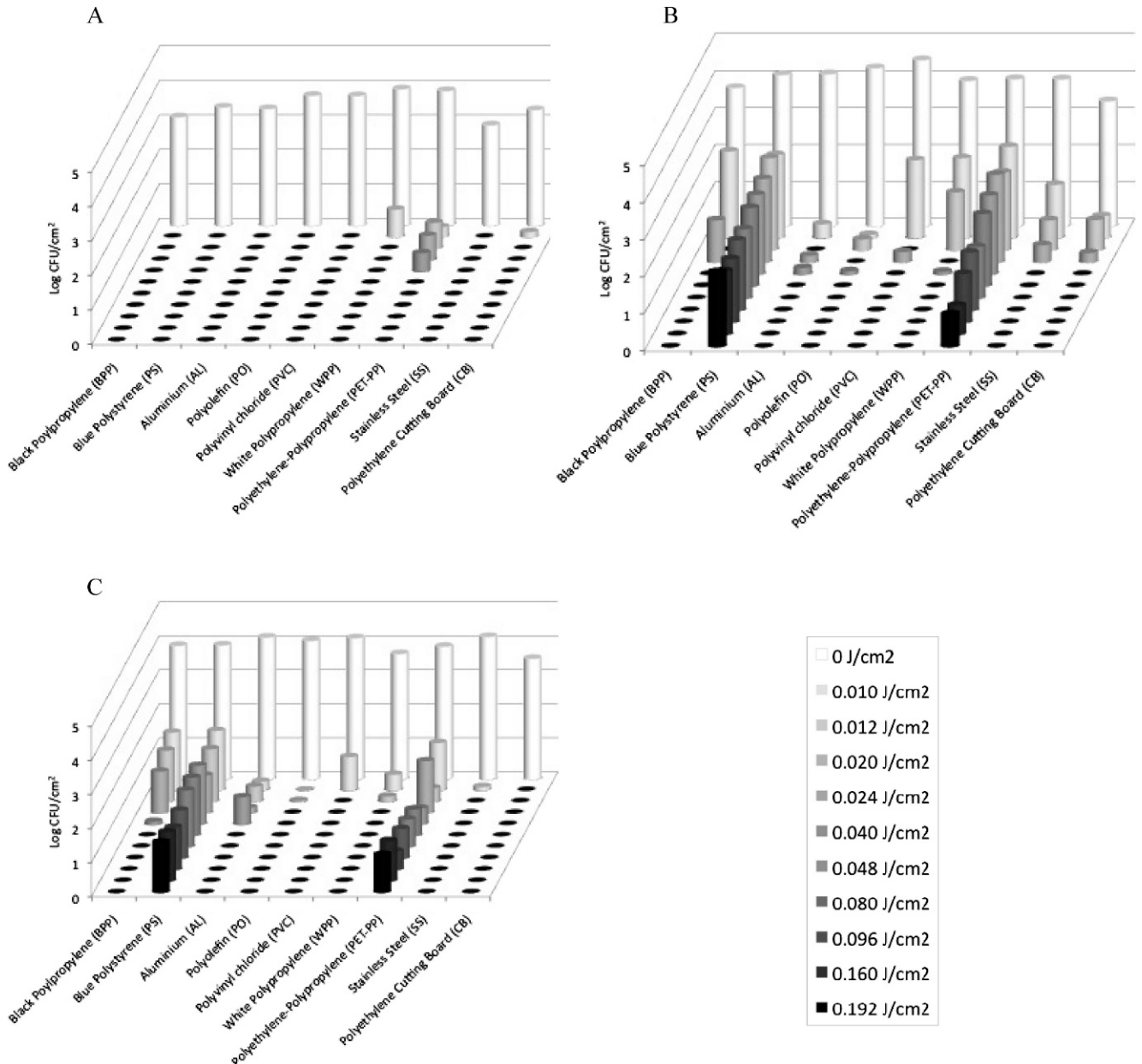

FIGURE 3. *UV inactivation of (A)* C. jejuni *(1147 DF), (B)* E. coli, *and (C)* Salmonella Enteritidis *on packaging materials and contact surfaces (UV-C doses, 0 to 0.192 J/cm^2).*

Respective doses required in the current study to achieve the same level of inactivation were much greater at 0.19 and 0.16 J/cm^2. This is most likely due to the properties of the treatment medium reducing the penetration ability of the UV light *(24)*.

UV treatment of raw poultry. For *Campylobacter,* a reduction of 0.76 log CFU/g was obtained on raw chicken fillet in the present study. This is in agreement with previous work by Isohanni and Lyhs *(12),* who investigated the effect of UV irradiation up to 32.9 $mW/s/cm^2$ (0.0329 J/cm^2) on raw broiler meat and reported a reduction of 0.7 log CFU/ml. Moreover, they also found greater inactivation (0.8 log CFU/ml) of *C. jejuni* on broiler skin following UV treatment, while the current study found the effectiveness of UV was reduced on skin compared to skinless fillet for all organisms investigated. The authors did not report if there were significant differences between skin and meat but did suggest that the observed difference may be due to the dry meat surface as a consequence of flaming before inoculation *(12)*. Other workers *(4)* reported a 1.26-log CFU/g reduction for *C. jejuni* on skinless chicken breast following UV irradiation of 5 kJ/m^2 (0.50 J/cm^2). The dose used for their study was almost three times greater than that used in the current study (0.192 J/cm^2), suggesting that increasing the UV dose may improve the decontamination potential of this technology for chicken. Although the reductions achieved for *Campylobacter* both in the published and present studies were modest, this technology could potentially be used as part of a *Campylobacter* control strategy in poultry. For example, quantitative microbial risk assessment models indicate that a 2-log reduction in *Campylobacter* levels on broiler carcasses should substantially reduce the risk of human exposure and associated illness *(10, 22)*. UV technology could therefore be applied as part of a sequential risk reduction strategy to achieve a worthwhile effect.

Color analysis of UV-treated raw poultry. Overall, no significant differences in the color of UV-treated chicken were observed, but some changes in the Hunter b values were detected. However, the latter would probably not be large enough to be visually noticeable and, excluding them, the results from the color analysis are in agreement with a number of studies that reported no significant changes in the color of chicken after UV treatment *(4, 12, 28)*. In contrast, other studies have reported significant changes following storage, although the changes were not thought to be visually detectable *(17)*.

UV treatment of bacteria on food contact surfaces and packaging materials. The present study has shown that UV light was able to reduce the levels of a range of organisms on packaging materials and on food contact surfaces and was most effective for reducing *C. jejuni* on the latter materials. In general, UV light was least effective when applied to organisms inoculated onto PET-PP films and onto PS. The relatively porous nature of the latter can facilitate penetration of bacteria below the surface of the material where shielding from the UV light may take place,

producing a shadowing effect that has been previously described for irregular surfaces *(24)*.

In conclusion, the current study demonstrates the potential of UV light for improving the microbiological safety of poultry. It has also shown UV treatment to be an effective decontamination method for packaging materials and surfaces associated with the preparation of raw chicken for sale, which could therefore reduce the risk of exposure to consumers. In relation to *Campylobacter,* a previously unreported variation in strain susceptibility to UV light has been demonstrated, and these findings emphasize the importance of strain selection for inactivation studies. UV has been approved by the FDA as a means for controlling surface microorganisms on food products. As there currently is no legislation prohibiting the use of UV for treating foods in the European Union, its use is dependent on relevant national regulations within individual member states. Overall, UV technology has the potential to be utilized effectively within the poultry industry to control pathogenic organisms.

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