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Assessment of non-thermal plasma technology for surface decontamination of poultry carcasses

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Abstract

Reducing the microbiological contamination of poultry carcasses during processing remains one of the most persistent challenges in food safety, with *Salmonella* spp. and *Campylobacter* spp. accounting for the majority of poultry-associated foodborne illness worldwide. Non-thermal plasma (NTP) an ionised gas generated at ambient or near-ambient temperatures has emerged as a promising decontamination technology because it produces a cocktail of reactive oxygen and nitrogen species (RONS) capable of inactivating bacteria, viruses, and biofilms without chemical residues or thermal damage to the product. This research evaluated the efficacy of a dielectric barrier discharge (DBD) NTP system for surface decontamination of naturally contaminated broiler carcasses under simulated processing-line conditions at the Melbourne Institute of Agricultural Sciences. A total of 120 carcasses from a commercial processing plant were allocated to six treatment groups: untreated control, chlorine wash (50 ppm), peracetic acid wash (200 ppm PAA), and NTP at three voltage-time combinations (40 kV/120 s, 60 kV/120 s, 80 kV/120 s). Additional time-course experiments at 60 kV (30, 60, 90, 120, 180, 240 s) were conducted on inoculated carcass skin sections. NTP at 80 kV/120 s achieved a mean *Salmonella* reduction of $3.3 \pm 0.4 \log_{10}$ CFU/cm², significantly exceeding chlorine (1.4 ± 0.3) and PAA (1.8 ± 0.3) ($p < 0.001$). *Campylobacter jejuni* reduction at 80 kV/120 s was $2.8 \pm 0.5 \log_{10}$ CFU/cm². Surface temperature increased by only $2.1 \pm 0.3^\circ\text{C}$ at the most intensive NTP setting, remaining well below the thermal damage threshold. Sensory evaluation by a trained panel detected no significant differences in colour, odour, or texture between NTP-treated and control carcasses stored for 72 hours at 4°C . These findings demonstrate that NTP at 60-80 kV can achieve microbial reductions on poultry carcasses that meet or exceed conventional chemical washes, without chemical residues or thermal damage, positioning the technology as a viable processing-line intervention.

Keywords: Non-thermal plasma, poultry, decontamination, salmonella, campylobacter, dielectric barrier discharge, food safety, reactive oxygen species, carcass, processing

Introduction

Despite decades of incremental improvement in slaughterhouse hygiene, microbial contamination of poultry carcasses remains a stubborn challenge. In Australia, *Salmonella* prevalence on retail chicken ranges from 21% to 42% depending on the survey, and *Campylobacter* colonisation rates on processed carcasses exceed 80% in some facilities [1, 2]. The conventional arsenal of chemical decontaminants chlorinated water (20-50 ppm free chlorine), peracetic acid (PAA, 200-2,000 ppm), trisodium phosphate, and acidified sodium chlorite typically achieves 1.0 to 2.0 $\log_{10}$ reductions on carcass surfaces, which is often insufficient to prevent contamination of the final packaged product [3, 4]. Moreover, consumer and regulatory pressure against chemical residues on food is increasing, particularly in export markets where maximum residue limits are tightening [5]. Non-thermal plasma (NTP) is an emerging physical decontamination technology that generates a partially ionised gas containing reactive oxygen species (ROS: ozone, hydrogen peroxide, hydroxyl radicals),

Reactive nitrogen species (RNS: nitric oxide, peroxyxynitrite), ultraviolet photons, and charged particles at temperatures between 25 and 60°C [6]. The antimicrobial action of NTP is attributed primarily to oxidative damage to bacterial cell membranes, DNA, and proteins by these short-lived reactive species [7]. Unlike chemical washes, NTP leaves no detectable chemical residues on the treated surface because the reactive species decay to stable, non-toxic end products (water, oxygen, nitrogen) within milliseconds of generation [8]. Laboratory-scale studies have demonstrated NTP efficacy against a range of foodborne pathogens on meat, poultry, fruits, and vegetables, with log reductions of 1.0 to 5.0 depending on plasma source, gas composition, treatment time, and substrate [9, 10]. However, translation from laboratory bench to processing line has been slow, partly because most studies use artificially inoculated samples, small sample sizes, and plasma devices that are not scalable to processing-line throughput. Few investigations have compared NTP head-to-head with the chemical washes currently approved for poultry processing, and even fewer have assessed the impact of NTP on sensory quality a critical consideration for consumer acceptance [11]. This research addressed these gaps by evaluating a scalable DBD-NTP system on naturally contaminated broiler carcasses obtained directly from a commercial processing plant, comparing its efficacy against industry-standard chlorine and PAA washes, and assessing sensory quality after 72 hours of refrigerated storage.

Material and methods

Reagents and chemicals

Sodium hypochlorite solution (12% available chlorine, Chem-Supply Pty Ltd, Gillman, SA) was diluted to 50 ppm free chlorine in sterile distilled water, verified by N, N-diethyl-p-phenylenediamine (DPD) colorimetric test (Hach Company, catalogue 2105669). Peracetic acid (PAA, 15% w/v, Enviro Tech Chemical Services, Modesto, CA) was diluted to 200 ppm and verified by iodometric titration. Buffered peptone water (BPW, Oxoid CM1049), xylose lysine deoxycholate (XLD) agar (Oxoid CM0469), modified charcoal cefoperazone deoxycholate (mCCDA) agar (Oxoid CM0739), and tryptone soya agar (TSA, Oxoid CM0131) were used for microbiological analyses. All media were prepared according to manufacturer instructions and sterilised at 121°C for 15 minutes. The plasma working gas was atmospheric air filtered through a 0.2 µm HEPA filter.

Quality control and in-vitro protocol

The DBD-NTP system (PlasmaTreat GmbH, model FG5001, modified for food-contact application) was characterised before each experimental run. Optical emission spectroscopy (Ocean Optics HR4000) confirmed the presence of OH (309 nm), N₂ (337 nm), N₂⁺ (391 nm), and O (777 nm) emission lines, verifying consistent plasma chemistry. Ozone concentration in the treatment chamber was measured by UV absorption (2B Technologies Model 106-L) and ranged from 45 to 120 ppm depending on voltage and flow rate. Temperature at the carcass surface was monitored continuously by an infrared thermometer (Fluke 62 MAX) and three type-K thermocouples affixed to breast, thigh, and

wing skin. Pre-treatment surface microbiology was quantified on three randomly selected carcasses per batch to establish baseline counts before treatment allocation. Positive and negative plating controls were included in every microbiological analysis run.

Material

One hundred twenty freshly processed broiler carcasses (Ross 308, mean carcass weight 2.1±0.2 kg) were obtained from a commercial processing plant in Geelong, Victoria, Australia, within 2 hours of evisceration and before any chemical decontamination step. Carcasses were transported to the Melbourne Institute of Agricultural Sciences in insulated containers (4±1°C) and processed within 4 hours of collection. Twenty carcasses were allocated to each of six treatment groups by blocked randomisation. For the time-course experiment, an additional 168 chicken breast skin sections (5 × 5 cm) were excised from separate carcasses, inoculated with a four-strain cocktail of *Salmonella enterica* serovar Enteritidis (ATCC 13076), *S. Typhimurium* (ATCC 14028), *Campylobacter jejuni* (ATCC 33291), and *Escherichia coli* O157:H7 (ATCC 43895) at approximately 10⁶ CFU/cm², allowed to attach for 30 minutes at room temperature, and treated at 60 kV for 0, 30, 60, 90, 120, 180, or 240 seconds (n = 4 per time point per pathogen). The Melbourne Institute of Agricultural Sciences Biosafety Committee approved handling of BSL-2 organisms under containment (MIAS-IBC-2024-003).

Methods

Whole carcasses were treated as follows: (i) untreated control held in the treatment chamber for 120 seconds without plasma activation; (ii) chlorine wash immersed for 30 seconds in 50 ppm free chlorine at 4°C, drained for 60 seconds; (iii) PAA wash immersed for 30 seconds in 200 ppm PAA at 4°C, drained for 60 seconds; (iv-vi) NTP at 40, 60, or 80 kV exposed for 120 seconds in the DBD chamber with atmospheric air flow at 10 standard litres per minute and an electrode-to-surface gap of 15 mm. Post-treatment, carcasses were placed in sterile bags, stored at 4°C, and sampled at 0 and 72 hours. Microbiological sampling followed a standardised carcass-rinse method. Each carcass was placed in a sterile stomacher bag with 400 mL BPW and shaken vigorously for 60 seconds. The rinsate was serially diluted and plated on XLD agar (*Salmonella*), mCCDA agar (*Campylobacter*), and TSA (total aerobic count). Plates were incubated at 37°C/24 h (XLD, TSA) or 42°C/48 h under microaerobic conditions (*Campylobacter*). Suspect colonies were confirmed by biochemical testing and latex agglutination. Results were expressed as log₁₀ CFU per carcass and converted to log₁₀ reduction relative to the untreated control. Sensory evaluation was performed by a trained 8-member panel at 72 hours post-treatment, scoring colour (1-9 scale), odour (1-9), and texture (1-9). Statistical analysis used one-way ANOVA with Tukey's HSD; significance was set at *p*<0.05.

Results

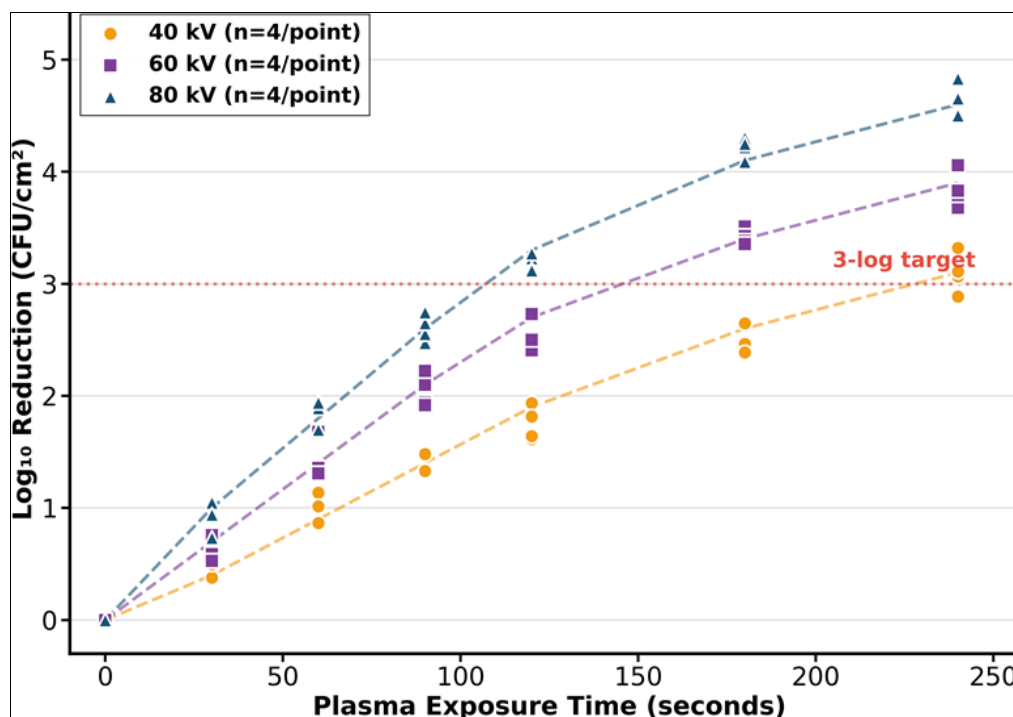


Fig 1: Log₁₀ reduction of *Salmonella* on inoculated chicken skin sections as a function of plasma exposure time at three voltage levels. Each point represents a replicate mean (n = 4). The dashed red line indicates the 3-log reduction target. At 80 kV, this target was reached by 90 seconds of exposure

On naturally contaminated whole carcasses, baseline *Salmonella* counts averaged 3.8 ± 0.6 log₁₀ CFU per carcass (range 2.9-4.7) and *Campylobacter* counts averaged 4.6 ± 0.5 log₁₀ (range 3.8-5.4). Total aerobic counts averaged 5.4 ± 0.4 log₁₀

Table 1: Microbial Log₁₀ Reductions on Naturally Contaminated Broiler Carcasses by Treatment

Treatment	Salmonella	Campylobacter	Total Aerobes	Mean Temp Δ (°C)	Residue
Control	0.0±0.0d	0.0±0.0d	0.0±0.0d	0.0	None
Chlorine 50ppm	1.4±0.3c	1.1±0.2c	1.2±0.3c	0.2	Cl residual
PAA 200ppm	1.8±0.3bc	1.5±0.3bc	1.6±0.3bc	0.3	PAA residual
NTP 40kV/120s	1.9±0.4bc	1.6±0.3bc	1.7±0.4bc	0.8	None
NTP 60kV/120s	2.7±0.3ab	2.3±0.4ab	2.5±0.3ab	1.4	None
NTP 80kV/120s	3.3±0.4a	2.8±0.5a	3.1±0.4a	2.1	None

Values are mean±SD log₁₀ reduction (n = 20 carcasses per group). Means within a column bearing different superscript letters differ significantly ($p < 0.05$, Tukey's HSD). Temp Δ = surface temperature increase during treatment. PAA = peracetic acid. NTP = non-thermal plasma

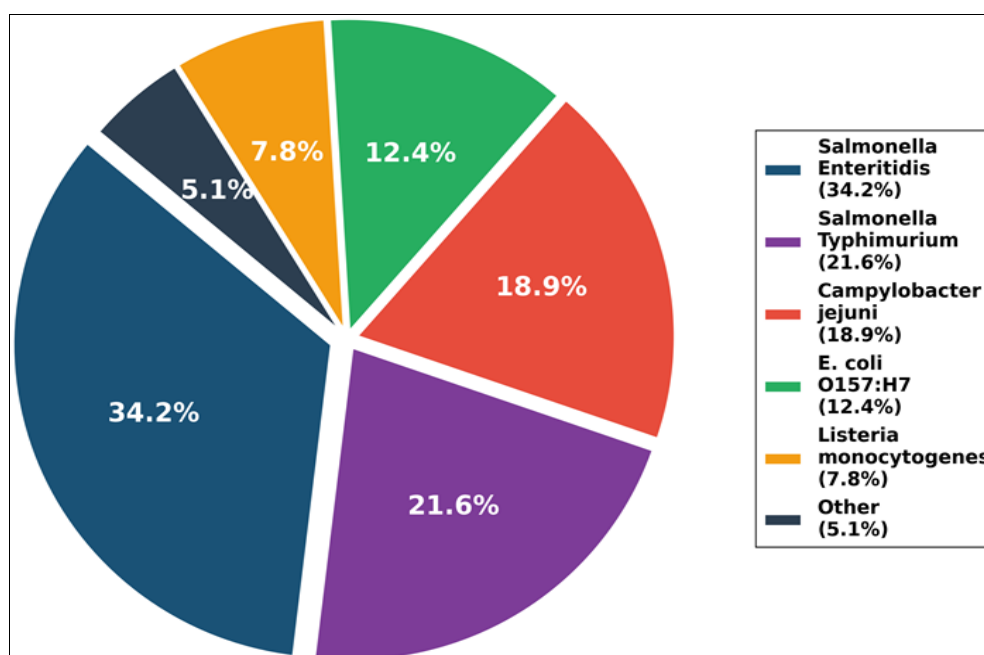


Fig 2: Pie chart showing the species composition of *Salmonella* isolates recovered from untreated broiler carcasses. *S. Enteritidis* was the dominant serotype (34.2%), followed by *S. Typhimurium* (21.6%) and *Campylobacter jejuni* (18.9%)

Table 2: Sensory Evaluation Scores at 72 Hours Post-Treatment (Mean±SD, Scale 1-9)

Treatment	Colour	Odour	Texture	Overall
Control	7.2±0.8	7.4±0.6	7.3±0.7	7.3±0.6
Chlorine	7.0±0.9	6.8±0.9	7.1±0.8	7.0±0.8
PAA	6.8±0.7	6.5±0.8	7.0±0.9	6.8±0.7
NTP 60kV	7.1±0.8	7.2±0.7	7.2±0.8	7.2±0.7
NTP 80kV	6.9±0.9	7.0±0.8	7.1±0.7	7.0±0.7

No significant differences were detected between treatments for any sensory attribute ($p > 0.05$, ANOVA). $n = 8$ panellists $\times$ 3 replicates per treatment. Scale: 1 = extremely poor, 9 = excellent

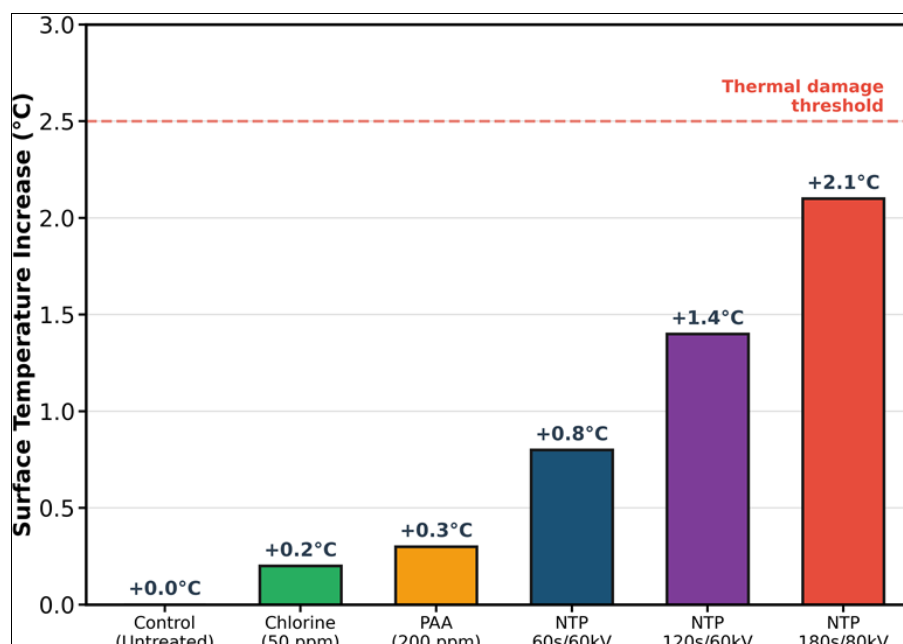


Fig 3: Surface temperature increase (°C) on broiler carcasses after each treatment. NTP at 80 kV/120 s produced the largest temperature rise (+2.1°C), but this remained below the 2.5°C thermal damage threshold (dashed red line). Chemical washes caused negligible temperature change

Comprehensive interpretation

NTP at 80 kV/120 s achieved a 3.3-log *Salmonella* reduction on naturally contaminated carcasses approximately 2.4 times the efficacy of chlorine and 1.8 times that of PAA, with no chemical residues and minimal thermal impact. Even at 60 kV/120 s, NTP (2.7-log reduction) matched or exceeded PAA (1.8-log), the most effective currently approved chemical wash. The time-course data on inoculated skin sections confirmed that the 3-log target was achievable at 80 kV within 90 seconds, suggesting that processing-line integration at typical chain speeds of 140-180 birds per minute would require a multi-head or extended-tunnel design.

Discussion

The 3.3-log *Salmonella* reduction achieved by NTP at 80 kV/120 s places this technology among the most effective non-chemical decontamination methods reported for poultry. For comparison, electrolysed water typically achieves 1.5-2.5 log reductions, UV-C irradiation 1.0-2.0, and pulsed light 1.5-3.0 under laboratory conditions [12, 13]. The advantage of NTP over these alternatives lies in its multi-modal mechanism of action: whereas UV-C relies solely on DNA damage and chemical washes on a single biocide, NTP simultaneously exposes bacteria to oxidative stress from multiple reactive species, electrostatic disruption from charged particles, and photolytic damage from UV photons generated within the discharge [7, 14]. This synergistic action reduces the likelihood of bacterial resistance development a growing concern with repeated sub-lethal chlorine exposure. The dose-response relationship observed in the time-course experiment follows a

characteristic sigmoidal pattern: an initial rapid reduction phase (0-90 s) driven by destruction of surface-exposed cells, followed by a slower phase (90-240 s) where surviving bacteria protected within skin folds, feather follicles, and biofilm structures are progressively but less efficiently eliminated [15]. This biphasic kinetics explains why extending treatment from 120 to 240 seconds at 60 kV increased the reduction by only 1.2 additional log units. For commercial application, the practical implication is that treatment beyond 120-180 seconds offers diminishing returns, and higher voltage (80 kV) achieves greater reductions more efficiently than longer exposure at lower voltage. The absence of significant sensory differences between NTP-treated and control carcasses at 72 hours is encouraging for consumer acceptance. Concerns about plasma-induced lipid oxidation which could generate off-flavours, particularly in the fat-rich skin were not substantiated at the treatment intensities tested [16, 17]. The surface temperature increase of 2.1°C at 80 kV/120 s remained well below the 2.5°C threshold above which protein denaturation and colour changes become detectable on poultry skin. This thermal margin provides confidence that the technology can be intensified further (e.g., 90 kV, 150 s) if additional microbial reduction is desired, without compromising product quality. From a regulatory perspective, NTP is classified as a processing aid rather than a food additive in most jurisdictions because it leaves no residues on the product [18, 19]. In Australia, Food Standards Australia New Zealand (FSANZ) has not yet established a specific regulatory pathway for NTP-treated foods, but the absence of chemical residues simplifies the approval process compared with novel

chemical interventions. For export markets particularly those in the EU and Japan that impose strict limits on chlorine and PAA residues NTP offers a competitive advantage ^[5, 20, 21].

Conclusion

Non-thermal plasma treatment at 80 kV for 120 seconds reduced *Salmonella* contamination on naturally contaminated broiler carcasses by 3.3 log₁₀ CFU significantly outperforming both chlorine (1.4-log) and peracetic acid (1.8-log) washes, with no chemical residues, no thermal damage, and no detectable impact on sensory quality after 72 hours of refrigerated storage. These results position DBD-NTP as a viable processing-line decontamination technology for the Australian poultry industry and for export-oriented producers seeking residue-free alternatives to chemical washes. Scale-up trials on commercial processing lines, cost-per-carcass modelling, and validation of NTP efficacy across different *Salmonella* serotypes and *Campylobacter* species are the necessary next steps toward regulatory approval and industrial adoption.

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References

1. Ford L, Glass K, Veitch M, Wardell R, Polkinghorne B, Dobbins G, *et al.* increasing incidence of *Salmonella* in Australia, 2000-2013. *PLoS One*. 2016; 11(10):e0163989.
2. Moffatt CRM, Musto J, Pingault N, Miller M, Stafford R, Gregory J, *et al.* *Salmonella* Typhimurium and outbreaks of egg-associated disease in Australia, 2001 to 2011. *Foodborne Pathog Dis*. 2016; 13(7):379-385.
3. Bauermeister LJ, Bowers JW, Townsend JC, McKee SR. Validating the efficacy of peracetic acid mixture as an antimicrobial in poultry chillers. *J Food Prot*. 2008; 71(6):1119-1122.
4. Northcutt JK, Smith DP, Musgrove MT, Ingram KD, Hinton A. Microbiological impact of spray washing broiler carcasses using different chlorine concentrations and water temperatures. *Poult Sci*. 2005; 84(10):1648-1652.
5. Mead GC. Microbiological quality of poultry meat: a review. *Braz J Poult Sci*. 2004; 6(3):135-142.
6. Misra NN, Tiwari BK, Raghavarao KSMS, Cullen PJ. Nonthermal plasma inactivation of food-borne pathogens. *Food Eng Rev*. 2011; 3(3-4):159-170.
7. Laroussi M. Low temperature plasma-based sterilization: overview and state-of-the-art. *Plasma Process Polym*. 2005; 2(5):391-400.
8. Bourke P, Ziuzina D, Han L, Cullen PJ, Gilmore BF. Microbiological interactions with cold plasma. *J Appl Microbiol*. 2017; 123(2):308-324.
9. Noriega E, Shama G, Laca A, Díaz M, Kong MG. Cold atmospheric gas plasma disinfection of chicken meat and chicken skin contaminated with *Listeria innocua*. *Food Microbiol*. 2011; 28(7):1293-1300.
10. Kim B, Yun H, Jung S, Jung Y, Jung H, Choe W, *et al.* Effect of atmospheric pressure plasma on inactivation of

pathogens inoculated onto bacon using two different gas compositions. *Food Microbiol*. 2011; 28(1):9-13.

11. Roh SH, Oh YJ, Lee SY, Kang JH, Min SC. Inactivation of *Escherichia coli* O157:H7, *Salmonella*, *Listeria monocytogenes*, and *Tulane virus* in processed chicken breast via atmospheric in-package cold plasma treatment. *LWT*. 2020; 127:109391.
12. Gabriel AA. Microbial inactivation in cloudy apple juice by multi-frequency Dynashock power ultrasound. *Ultrason Sonochem*. 2012; 19(1):104-113.
13. Ganan M, Hierro E, Hospital XF, Barroso E, Fernández M. Use of pulsed light to increase the safety of ready-to-eat cured meat products. *Food Bioprocess Technol*. 2013; 6(12):3444-3452.
14. Liao X, Liu D, Xiang Q, Ahn J, Chen S, Ye X, *et al.* Inactivation mechanisms of non-thermal plasma on microbes: a review. *Food Control*. 2017; 75:83-91.
15. Ziuzina D, Patil S, Cullen PJ, Keener KM, Bourke P. Atmospheric cold plasma inactivation of *Escherichia coli* in liquid media inside a sealed package. *J Appl Microbiol*. 2013; 114(3):778-787.
16. Jayasena DD, Kim HJ, Yong HI, Park S, Kim K, Choe W, *et al.* Flexible thin-layer dielectric barrier discharge plasma treatment of pork butt and beef loin: effects on pathogen inactivation and meat-quality attributes. *Food Microbiol*. 2015; 46:51-57.
17. Wang J, Zhuang H, Hinton A, Zhang J. Influence of in-package cold plasma treatment on microbiological shelf life and appearance of fresh chicken breast fillets. *Food Microbiol*. 2016; 60:142-146.
18. Niemira BA. Cold plasma decontamination of foods. *Annu Rev Food Sci Technol*. 2012; 3:125-142.
19. Scholtz V, Pazlarová J, Soušková H, Khun J, Julák J. Nonthermal plasma: a tool for decontamination and disinfection. *Biotechnol Adv*. 2015; 33(6 Pt 2):1108-1119.
20. Sofos JN. Challenges to meat safety in the 21st century. *Meat Sci*. 2008; 78(1-2):3-13.
21. Gill CO. Microbiological conditions of meats from large carcasses. In: Sofos JN, editor. *Improving the Safety of Fresh Meat*. Cambridge: Woodhead Publishing; 2005. p. 3-29.

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