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An assessment of steam pasteurization and hot water immersion treatments for the microbiological decontamination of broiler carcasses

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Abstract

The effects of steam pasteurization and hot water immersion treatments on the microbiological profile of whole broiler carcasses and thigh pieces were investigated. Hot water immersion of broiler thigh pieces for 10 s at 80°C and 85°C resulted in significant reductions of 1.09 and 1.25 cfu g^{-1} in total viable bacteria ($P \leqslant 0.05$). Significant decreases in the numbers of thermophilic *Campylobacter* were observed on artificially contaminated skin samples following 10 s immersions in water maintained at 75°C, 80°C or 85°C ($P \leqslant 0.05$). A 20 s immersion in water at 80°C and 85°C resulted in significant reductions in the recovery of total viable bacteria, *Enterobacteriaceae* and *Campylobacter* ($P \leqslant 0.05$).

Statistically insignificant reductions in the counts of total viable bacteria together with levels of *Enterobacteriaceae* and thermophilic *campylobacters* were observed on broiler carcasses exposed to atmospheric steam at 90°C for 12 s when compared to untreated control carcasses. When the exposure time in the steam pasteurization chamber was increased to 24 s, significant reductions in the counts of these organisms were observed with 0.75, 0.69 and 1.3 $\log_{10}$ cfu g^{-1} decreases in total viable counts, *Enterobacteriaceae* and *campylobacters*, respectively ($P \leqslant 0.05$). Visible damage to the outer epidermal skin tissue was observed in both the hot water immersion and steam pasteurization treatments used in the current study.

Keywords: Decontamination; Stream; Immersion; *Campylobacter*

1. Introduction

The levels of enteric illness cases in humans resulting from the consumption of pathogen-contaminated foods has remained high in developed countries worldwide. These foodborne infections have frequently been attributed to the consumption of raw or undercooked poultry meat (Zivkovic et al., 1989; Tompkin, 1994; Skirrow, 1991). Processed raw poultry carcasses have often been reported to be contaminated with *Salmonella* or *Campylobacter* and, significantly, these pathogens are the most frequently reported causes of bacterial foodborne illness in humans in many countries, including Ireland (Cooper, 1994; Truszczynski and Hoszowski, 1995; Anon., 1997; Foley et al., 2001). Bryan and Doyle (1995) found that the prevalence of *Salmonella* on poultry carcasses varied from 2% to 100% with an estimated median prevalence of 30%. The prevalence of *Campylobacter*-contaminated carcasses reported previously has also varied widely with rates ranging from 3% to 100% (Kwiatek et al., 1990; Berndtson et al., 1996; Cantor, 1997).

Microbial contamination of broiler carcasses can occur during any of the pre- and/or post-harvest phases of commercial production and processing. However, it has been suggested that the application of longitudinally integrated preventive approaches using Hazard Analysis Critical Control Point (HACCP)-based systems represents the most effective means of minimizing pathogen infection in broiler flocks and subsequent carcass contamination (Tompkin, 1994). In order to achieve this long-term objective of pathogen-free poultry meat,

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risks associated with pathogen infection in live poultry must be reduced through the implementation of stringent controls in feed mills, hatcheries, breeder and production farms (Anon., 1997). However, in the interim absolute control of microbial hazards cannot be guaranteed during broiler processing as no elimination steps are used currently in Irish poultry slaughter plants.

In recent years, carcass decontamination technologies have been investigated as an additional processing step in order to reduce the levels of microbiological hazards of public health significance. These can be classified either as chemical or physical decontamination methodologies including the use of ozonated or superchlorinated water (Waldroup, 1993; Gorman et al., 1995; Whyte et al., 2001), hydrogen peroxide (Fletcher et al., 1993), a range of organic acids (Bautista et al., 1997; Hwang and Beuchat, 1995), polyphosphates (Rodriguez de Ledesma et al., 1996; Whyte et al., 2001), hot water (Cox et al., 1974; Kochevar et al., 1997; Graves Delmore et al., 1997; Berrang et al., 2000) and steam pasteurization (Kozempel et al., 2000).

The application of chemical decontaminants in poultry processing is permitted in the United States; however, their use in commercial plants in European Union countries is currently prohibited. However, physical decontamination technologies such as hot water immersion and steam pasteurization treatments are permissible in the E.U. The EC Scientific Committee on veterinary measures relating to public health in its report "Benefits and Limitations of Antimicrobial Treatments for Poultry Carcasses" concluded that the use of either hot water or steam on carcasses was safe and that temperatures in excess of 85°C were necessary to achieve significant reductions in microbial counts (Anon., 1998). Numerous research studies have been carried out detailing the decontamination performances of both steam and hot water immersion treatments of beef carcasses; however, relatively few studies have been published to date assessing their effectiveness on broilers. Furthermore, most studies have not included assessments of the effects of thermal treatments on the visual appearance of broiler carcasses. The current studies were undertaken to investigate the efficacy of a number of hot water immersion treatments and a commercial steam pasteurization unit as potential methods for the decontamination of processed broiler carcasses. The effect of these treatments on the visual appearance was also determined in the current study.

2. Methods

2.1. Trial 1—hot water immersion

Seventy packaged broiler thighs were purchased from a local retail outlet. The thighs were divided into two groups with 35 thighs designated as "naturally contaminated" (NC) and the remaining 35 thighs marked as "artificially contaminated" (AC). An overnight culture of *Campylobacter jejuni* (originally isolated from a broiler carcass) was prepared by inoculating 21 of Nutrient broth No. 2 (Oxoid CM 67) containing a growth supplement (Oxoid SR84E) and incubating at 37°C for 24 h. The cell concentration in the overnight culture was confirmed and the AC thighs were artificially inoculated. The broiler thighs designated as AC were each immersed in the overnight *C. jejuni* culture for 60 s and were then allowed to drain for 30 min. Five of the NC and AC broiler thighs were designated as control samples and received no further treatments. The remaining 60 NC and AC thighs were subdivided into groups of five and subjected to the following immersion treatments using three separate temperature-controlled and preheated water baths: (i) 10 s at 75°C, (ii) 10 s at 80°C, (iii) 10 s at 85°C, (iv) 20 s at 75°C, (v) 20 s at 80°C and (vi) 20 s at 85°C. Following each treatment, 10 g of skin were removed from the thighs and appropriately labelled before microbiological analysis was carried out.

2.2. Trial 2—steam pasteurization

A total of 30 broiler carcasses were obtained directly from a leading Irish processing plant which had a daily throughput of approximately 90 000 broilers. All 30 carcasses were obtained from within the same flock. The carcasses were removed from the processing line immediately prior to the final carcass wash and stored at $\leqslant +4$°C overnight. Subsequently, the carcasses were transported under chilled conditions to a licensed beef export abattoir which had a steam pasteurization unit (Frigoscandia, Bedford, UK) installed in-line immediately preceding chilling. The steam pasteurization system processed a single carcass side per cycle. Once the carcass was introduced to the chamber, the doors were sealed automatically and the three stages of the process commenced, namely, water removal, steam application and cold water spraying as described previously (Nutsch et al., 1998). The pasteurization unit was programmed to expose beef carcass sides to steam at 90°C for 12 s, in an enclosed non-pressurized chamber, followed by a cold water spray used to remove surface heat acquired during pasteurization. Ten of the broiler carcasses were set aside and labelled as untreated controls. The remaining 20 carcasses were subdivided into two groups each containing 10 broilers. The carcasses in one of these groups were passed through the pasteurizer for 12 s at 90°C which was identical to the process parameters used for beef carcasses in the test plant. It was decided to increase the exposure time to 24 s for the second group of carcasses using steam at the same temperature in order to assess the bactericidal

effect of extended exposure to steam. Previous studies using steam at temperatures ranging from 82°C and 100°C have resulted in significant reductions in *Listeria monocytogenes*, *Salmonella typhimurium*, *Enterobacteriaceae* and *Escherichia coli* on beef carcasses with exposure times of 6.5–15 s being used (Phebus et al., 1997; Nutsch et al., 1998). All of the carcasses were subsequently transported to the laboratory at a temperature of $\leqslant +4$°C and laboratory analysis was carried out later on the same day.

2.3. Microbiological analysis—Trial 1

The overnight culture of *C. jejuni* was enumerated by making up serial dilutions in 9 ml aliquots of 0.1% petone-water. Using a spiral plater (Don Whitely Scientific, Yorkshire, UK) 0.1 ml volumes were plated out in duplicate on to modified CCDA (Oxoid, CM739) containing a selective supplements (Oxoid, SR 155E and SR 84E). After microaerophilic incubation at 42°C for 48 h, the plates were counted and the viable cell concentration was confirmed at 4.88 $\log_{10}$ cfu ml^{-1}.

Following the various immersion treatments, 10 g samples of skin were removed aseptically from each of the broiler thighs and stomached (Lab Blender 400 series, Seward Medical, UK) in 20 ml volumes of 0.1% peptone-water for 1 min. Each of the samples was then analysed quantitatively for total viable counts (TVC) at 37°C, *Enterobacteriaceae* and thermophilic *campylobacters* using the spiral plater as described previously. TVCs were determined using Standard Plate Count agar (Oxoid, CM 463) with duplicate plates incubated at 37°C for 48 h. *Enterobacteriaceae* counts were determined using duplicate plates of violet red bile glucose agar (Oxoid, CM 485) which were incubated at 37°C for 18–24 h. Characteristic purple round colonies with a purple halo were counted as *Enterobacteriaceae*. Levels of *Campylobacter* spp. were assessed using a direct plating technique on modified CCDA plates. *Campylobacter* counts in NC samples were determined by plating out the initial 1:3 dilution. Further dilutions of 10^{-1} and 10^{-2} were used in order to estimate *Campylobacter* counts from the artificially contaminated samples. All modified CCDA plates were incubated microaerophilically at 42°C for 48 h. Following incubation, 35 suspect colonies were counted and confirmed using colony morphology, Gram stain, and biochemical tests which included hippurate hydrolysis, indoxylacetate hydrolysis and urease activity. The initial 1:3 dilutions from all of the samples were used to plate out for TVCs and *Enterobacteriaceae* counts in the control, AC and NC samples.

Finally, the prevalence of *Campylobacter* spp. on all skin samples was carried out by stomaching 10 g of skin in 90 ml of Preston selective enrichment broth (Oxoid, CM 67) to which appropriate growth and selective supplements were added (SR 84E and SR 204E). The Preston broths were incubated at 42°C for 24 h and subcultured subsequently on to modified CCDA and processed as before.

2.4. Microbiological analysis—Trial 2

Ten gram samples of breast skin were removed aseptically from the untreated control and steam pasteurized carcasses. Each of the carcass skin samples were diluted initially 1:2 by adding 10 ml of 0.1% peptone-water and stomached for 1 min. *Enterobacteriaceae* and thermophilic *Campylobacter* counts were determined by plating out 0.1 ml volumes of the 1:2 dilutions in duplicate on to violet red bile glucose and modified CCDA agars using the spiral plater as described. A further 10 fold dilution was prepared by adding 80 ml volumes of peptone-water to each of the stomached samples which was used to inoculate the TVC plates.

The prevalence of *campylobacters* on the skin samples was determined by adding 50 ml of the 1:10 dilutions to 50 ml aliquots of double strength Preston broth. In addition, the prevalence of *campylobacters* on the inner surfaces of the visceral cavity in each broiler carcass was also determined. An area of approximately 25 cm^2 was swabbed in each cavity and the swabs were then added to 10 ml volumes of Preston broth. The broths were then vortexed for 30 s and incubated for 24 h at 42°C before subculturing on to modified CCDA agar. *Campylobacter* counts and prevalences were determined using the techniques described for Trial 1.

2.5. Statistical analysis

All bacterial counts obtained in Trials 1 and 2 were transformed to $\log_{10}$ values for subsequent data analysis. The effect of the various immersion and steam pasteurization treatments on bacterial counts was compared statistically using unpaired Student's *t*-tests with significance defined at the 95% level ($P \leqslant 0.05$).

3. Results

3.1. Trial 1—hot water immersion

Immersion in hot water of the naturally contaminated samples for 10 s at both 80°C and 85°C significantly reduced total viable counts with mean reductions of 1.09 and 1.25 $\log_{10}$ cfu observed, respectively, when compared to the corresponding control samples ($P \leqslant 0.05$). Statistically significant ($P \leqslant 0.05$) reductions in *Campylobacter* counts were observed for artificially contaminated samples treated for 10 s at all three immersion temperatures (Table 1). Interestingly, corresponding

Table 1
Effects of hot water immersion treatments on total viable counts (TVC 37°C), *Enterobacteriaceae* and thermophilic *Campylobacter* counts on broiler skin samples (Trial 1)

Treatment	TVC 37°C[a]		*Enterobacteriaceae*[a]		*Campylobacter*[a]		% *Campylobacter* positive	
	NC[b]	AC[c]	NC	AC	NC	AC	NC	AC
Controls	5.01±0.48	4.92±0.32	3.82±0.39	3.94±0.31	2.68±0.61	3.32±0.49	100[d,e](5/5)	100 (5/5)
10 s @ 75°C	4.49±0.21	4.74±0.22	3.66±0.75	3.88±0.19	2.85±0.67	2.40±0.63[f]	80 (4/5)	80 (4/5)
10 s @ 80°C[g]	3.92±0.35[f]	4.49±0.44	3.48±0.21	3.80±0.62	2.41±0.67	2.48±0.64[f]	100 (5/5)	100 (5/5)
10 s @ 85°C[g]	3.76±0.17[f]	4.62±0.40	3.47±0.44	3.60±0.40	2.25±0.29	2.24±0.41[f]	100 (5/5)	100 (5/5)
20 s @ 75°C[g]	4.20±0.90	4.31±0.17	3.36±0.83	3.59±0.56	2.04±0.68	2.45±0.38[f]	100 (5/5)	100 (5/5)
20 s @ 80°C[h]	3.64±0.34[f]	4.20±0.36[f]	2.98±0.72[f]	3.42±0.34[f]	1.71±0.46[f]	1.55±0.32[f]	100 (5/5)	100 (5/5)
20 s @ 85°C[h]	3.65±0.75[f]	3.79±0.60[f]	2.84±0.60[f]	3.29±0.77[f]	1.43±0.31[f]	1.43±0.26[f]	100 (5/5)	100 (5/5)

Note: $n = 5$ skin samples per treatment group.
± = standard deviation.
[a] Results expressed as $\log_{10}$ cfu g^{-1} of broiler thigh skin.
[b] NC = naturally contaminated broiler thigh samples.
[c] AC = artificially contaminated broiler thigh samples.
[d] Number of *Campylobacter* positive samples/total number of samples analysed per treatment group.
[e] Isolates confirmed as *C. jejuni* on naturally contaminated carcasses.
[f] Denotes statistical significance in counts between treatment groups compared to corresponding controls ($P \leqslant 0.05$).
[g] Denotes moderate degree of deterioration in physical appearance of broiler skin due to immersion treatments.
[h] Denotes extensive degree of deterioration in physical appearance of broiler skin due to immersion treatments.

Campylobacter counts did not alter significantly for naturally contaminated samples when compared to controls. No significant reductions in *Enterobacteriaceae* counts were observed for any of the samples treated for 10 s in any of the three temperature treatments.

The extended immersion treatments of 20 s resulted in significant reductions in the counts of organisms on both naturally and artificially contaminated skin samples. Total viable counts (37°C), *Enterobacteriaceae* and *Campylobacter* counts were all significantly lower on samples immersed for 20 s at either 80°C or 85°C ($P \leqslant 0.05$). From the data presented in Table 1, it can be seen that significantly lower counts of *Campylobacter* were also observed in artificially inoculated samples immersed for 20 s at 75°C ($P \leqslant 0.05$). The qualitative prevalence of *campylobacters* on all treated carcasses remained high when compared with corresponding controls. The percentage of *Campylobacter*-positive skin samples remained at 100% in all treated samples with the exception of the immersion treatment at 75°C for 10 s.

The immersion of broilers in hot water at temperatures of $\geqslant$75°C for either 10 or 20 s was sufficient to cause moderate-to-severe damage to skin resulting in discoloration and an overall deterioration in their appearance (Table 1).

3.2. Trial 2—steam pasteurization

The decontamination effects of exposing carcasses to pasteurizing steam appeared to be time dependent. An exposure time of 12 s at 90°C resulted in insignificant mean reductions of 0.43, 0.61 and 0.46 $\log_{10}$ cfu g^{-1} for total viable counts, *Enterobacteriaceae* and thermophilic *campylobacters*, respectively (Table 2). When the exposure time for carcasses in the pasteurization unit was increased to 24 s using 90°C steam, significant mean reductions of 0.75, 0.69 and 1.3 $\log_{10}$ cfu g^{-1} were observed for total viable counts, *Enterobacteriaceae* and *campylobacters*, respectively ($P \leqslant 0.05$).

The prevalence of *Campylobacter* on the breast skin samples of untreated control carcasses, and carcasses treated for 12 and 24 s was 90%, 90% and 60%, respectively. Lower prevalences of *Campylobacter* were observed from visceral cavity swabs taken from untreated control group carcasses and those treated for 12 and 24 s with 70%, 60% and 40% observed, respectively (Table 2).

Both of the steam treatments used in this study resulted in damage to the outer epidermal layer of the skin and a consequent deterioration in the visual appearance. It was found that longer exposure times of carcasses in the steam pasteurization unit effected more damage to the skin (Table 2).

4. Discussion

The use of hot water as a potential decontamination procedure for poultry carcasses during processing was investigated in the current study. The mechanisms of hot water immersion and washing are twofold; firstly there is a lethal effect caused by heat and secondly, the heated water facilitates the detachment and removal of bacteria

Table 2
The effect of steam pasteurization on total viable counts (TVC 37°C), *Enterobacteriaceae* and thermophilic *Campylobacter* counts on broiler carcasses

Treatment	Visual appearance	TVC 37°C	Mean count ($\log_{10}$) cfu g^{-1}		% *Campylobacter* positive[a]	
			Enterobacteriaceae	*Campylobacter*[a]	External skin	Visceral cavity swab
Control Group 1	—	4.71 ± 0.34	3.65 ± 0.23	2.14 ± 0.47	90 (9/10)	70 (7/10)
Group 2 (12 s @ 90°C)	[b]	4.28 ± 0.46	3.04 ± 0.32	1.68 ± 0.53	90 (9/10)	60 (6/10)
Group 3 (24 s @ 90°C)	[c]	3.96 ± 0.28[d]	2.96 ± 0.27[d]	0.84 ± 0.42[d]	60 (6/10)	40 (4/10

Note: $n = 10$ broiler carcasses per treatment group.
± = standard deviation.
[a] Isolates confirmed as *C. jejuni*.
[b] Denotes moderate degree of deterioration in physical appearance of broiler skin due to immersion treatments.
[c] Denotes extensive degree of deterioration in physical appearance of broiler skin due to immersion treatments.
[d] Denotes statistical significance in counts between treatment groups when compared to corresponding controls ($P \leqslant 0.05$).

from the skin surfaces (Bolder, 1997). In considering adequate water temperatures for carcass decontamination, it must be noted that enteric micro-organisms such as *E. coli* or *Salmonella* were found to be more resistant to hot water when attached to poultry skin than when they were suspended freely in water (Notermans and Kampelmacher, 1975). In the case of the present study, immersion in hot water maintained at 75°C for 10 s did not alter the appearance of the broiler thighs examined. Immersion of samples at 80°C and 85°C for 10 s resulted in significant reductions in total viable counts in naturally contaminated broiler thigh samples. All three temperatures at 10 s exposure time were also sufficient to reduce significantly *Campylobacter* counts on artificially contaminated samples; however, no significant reductions were observed for corresponding naturally contaminated samples (Table 1). A possible explanation for this observation is that the time of exposure to contamination prior to the application of decontamination treatments has been shown to influence bacterial attachment and the efficacy of the subsequent decontamination processes (Lillard, 1985; Cabedo et al., 1996, 1997). Counts of *Enterobacteriaceae* as faecal indicator organisms were not altered significantly when samples were immersed in any of the three temperature treatments for 10 s. These results are in agreement with the findings of Berrang et al. (2000) who concluded that post-scald immersion treatments gentle enough so as not to alter carcass appearance did not reduce effectively either *Campylobacter*, *E. coli* or coliform bacterial counts. Goksoy et al. (2001) reported insignificant reductions in *E. coli* counts on chicken breast samples immersed in water held at 70°C for 9 s, which agreed with the findings of the current study. Yang et al. (2001) in contrast reported significant reductions in the levels of *campylobacters* present on broiler skin immediately following immersion scalding at 60°C. However, it must be noted that typical scalding times used in commercial processing plants between 90 and 150 s would result in the destruction of greater numbers of this pathogen. Samples held for 10 s at either 80°C or 85°C caused a deterioration in the appearance of the broiler samples with a cooked coloration formed on the skin surfaces.

A longer immersion time of 20 s applied to artificially contaminated broiler thigh samples using the same temperatures as before resulted in significant reductions in the counts of *campylobacters* ($P \leqslant 0.05$). The higher temperature treatments of 80°C and 85°C for 20 s were required to reduce significantly the total viable counts together with the levels of *Enterobacteriaceae* and *Campylobacter* counts on naturally contaminated samples. Interestingly, the prevalence of *campylobacters* on all thigh samples remained high following the various immersion treatments when compared with untreated control samples (Table 1). Previous studies have investigated the use of various hot water immersion time–temperature combinations. Rodriguez de Ledesma et al. (1996) reported significant reductions in the levels of *S. typhimurium*, *S. aureus* and *L. monocytogenes* when chicken wings were dipped in water at 95°C for 5 s. Therefore, immersion in hot water using the treatments described above can, at best, reduce *Campylobacter* counts but fails to completely eliminate this pathogen from broiler skin surfaces. In addition, some of the 10 s and all of the 20 s immersion treatments caused a deterioration in the appearance of the skin on the broiler thigh pieces. The skin on the affected broiler thigh skin samples showed a slightly "cooked" appearance. The extent of the "cooked" presentation increased when the more severe water temperatures and immersion times were used. It is suggested on this basis that its adoption by commercial companies is not currently feasible as the deterioration in carcass appearance would be objectionable to consumers.

The exposure of whole broiler carcasses to unpressurized steam at 90°C for 12 s did not reduce significantly the total viable counts, or the levels of *Enterobacteriaceae* and *Campylobacter* (Table 2). However, when the exposure time was increased to 24 s, significant reductions were observed for all three categories of organism

enumerated in this study. In addition, the qualitative prevalence of *campylobacters* recovered from skin samples decreased from an initial level of 90% to 60%. *Campylobacter* contamination in the visceral cavities of the carcasses decreased from 70% for controls to 40% for carcasses treated to 24 s in the steam pasteurization unit. This finding has been acknowledged previously (Bolder, 1997). Kozempel et al. (2000) reported mean reductions in *E. coli*, coliforms and total viable counts ranging from 0.5 to 1.0 $\log_{10}$ cfu g^{-1} when carcasses were exposed to steam at 138°C for 0.1 s. Davidson et al. (1985) observed mean reductions between 1 and 3 $\log_{10}$ in total viable counts on broilers exposed to 180–200°C. Interestingly, no marked reduction in the prevalence of *Salmonella* was observed which is similar to our observations with *Campylobacter*. James et al. (2000) reported mean $\log_{10}$ reductions of 1.65 for total viable counts on broiler breast skin exposed to steam at 100°C for 10 s. Mean reductions of 4 $\log_{10}$ in *Listeria innocua* counts were observed for broiler samples initially inoculated with 10^7 cfu which were exposed to steam at 145°C for 25 ms (Morgan et al., 1996a, b). In addition, these authors observed no significant deterioration in the surface appearance of the treated broiler carcasses. As with most chemical and physical decontamination procedures, no significant extensions to product shelf-life have been observed in previous studies (Cox et al., 1974; James et al., 2000).

Both the time–temperature combinations used in the current steam pasteurization study were sufficient to cause damage to the outer epidermal layers of the broiler skin and a consequent deterioration in carcass appearance. The skin showed a noticeable discoloration with the formation of a more yellowed pigmentation and numerous breaks or discontinuities on the outer epidermis. This cracking of the epidermis also resulted in a slightly desiccated appearance with clumping of skin and uneven edges.

Several studies have demonstrated the significant efficacy of steam as a pastuerizing agent for dressed beef carcasses (Phebus et al., 1997; Nutsch et al., 1998). The decontamination performance of steam on broiler carcasses would appear from this study to be less effective. This may be a result of the highly folded and creviced nature of broiler skin which could protect micro-organisms from the lethal effects of the heat treatment.

The results of the current study demonstrate the potential of thermal processing steps such as hot water immersion or steam pasteurization to reduce significantly the levels of contamination by enteric pathogens on broiler carcasses. The deterioration in the appearance of carcass surfaces using the parameters used in the current study would deter the widespread commercial dissemination of this technology. However, from previous studies, it is suggested that ultra-high temperature ultra-short time treatments would be more suited for the non-destructive decontamination of broiler carcasses. In conclusion, it is suggested that either hot water immersion or steam pasteurization of processed broiler carcasses could be used as an effective intervention measure to control contamination by enteric pathogens of public health significance. As there are no legislative restraints applicable to this technology within the European Union, it is suggested that further research be carried out to optimize time–temperature profiles which could maximize the bactericidal effects and minimize damage to skin surfaces.

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