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ORIGINAL ARTICLE

Rapid desiccation with heat in combination with water washing for reducing bacteria on beef carcass surfaces

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A series of experiments were conducted to determine the effectiveness of rapid desiccation with dry heat at one or two points in the slaughter process to reduce bacterial contamination on beef carcass surfaces. In the first set of experiments, several combinations of desiccation and water washes were examined. Beef surfaces were inoculated with bovine feces and water washed (IW; 125 psi, 15 s, 35°C); desiccated (400°C, 15 s) before inoculation and subjected to a water wash ($D_{15}^{400°C}$ IW); inoculated, water washed and desiccated for 30 s ($IWD_{30}^{400°C}$); or desiccated, inoculated, water washed, and desiccated for 30 s ($D_{15}^{400°C}$ IW $D_{30}^{400°C}$). Samples treated with $D_{15}^{400°C}$ $IWD_{30}^{400°C}$ exhibited the lowest populations of APC, coliforms, and Escherichia coli*. When* E. coli *O157:H7,* Salmonella typhimurium, Listeria innocua *and* Clostridium sporogenes *were inoculated on to beef surfaces (3·30, 2·61, 3·97, and 3·63 log_{10} CFU/cm², respectively) and monitored following treatments with $D_{15}^{400°C}$ $IWD_{30}^{400°C}$, none of the organisms were detected. To minimize surface discoloration, an additional set of experiments were conducted using less heat (300°C) for shorter times. When desiccation (300°C) was conducted for 10, 12, or 15 s prior to fecal contamination and followed by a water wash ($D_{10,12,15}^{300°C}$ IW), it was demonstrated that none of the treatments were significantly different from the others for reducing APC from shortplates; however, the 10 s treatment was preferred for its shorter time. When desiccation for 10 s was combined with water washing and a second desiccation step (300°C) for 15, 20, or 25 s ($D_{10}^{300°C}$ $IWD_{15,20,25}^{300°C}$), populations of APC, coliforms, and* E. coli *were reduced to the greatest extent when the second desiccation step was applied for 25 s. This study is the first to report that water washing in combination with rapid desiccation with dry heat at one or two points in the slaughter process is more effective than water washing alone for reducing bacterial contamination on beef surfaces.*

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Introduction

The application of heat is not an original or novel intervention for reducing undesirable bacteria on meat animal carcasses. Numerous studies have demonstrated the effect of moist heat in the form of hot water (80–96°C) for reducing aerobic plate counts (APC) on meat carcasses (Barkate et al. 1993, Davey

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and Smith 1989, Patterson 1970). Other recent studies have demonstrated that the application of a steam vacuum in conjunction with warm/hot water washes effectively reduced populations of APC, coliforms, *Escherichia coli*, and pathogens (Dorsa et al. 1996a, 1996b, 1997). Additional studies also have demonstrated the effectiveness of a steam pasteurization process for reducing bacterial populations on beef surfaces (Nutsch et al. 1997, Phebus et al. 1997). Based on this information, moist heat interventions, such as hot water or steam, or a combination, are currently being used by some sectors of the meat industry to improve the microbiological profile of animal carcasses (USDA, FSIS).

When fecal contamination does occur on carcass surfaces and moist heat interventions are employed, there is a possibility that some bacteria may not be affected. Specifically, readministration of moist heat may cause the collagen mat present on the tissue surface to expand and possibly impede the penetration of heat to the bacteria (Dorsa et al. 1996b). The authors speculated that the application of a nonhydrating intervention, administered before the utilization of moist heat, may improve the subsequent intervention's ability to reduce bacterial populations (Dorsa et al. 1996b).

In this study, the use of rapid desiccation with heat, before inoculation, immediately after water washes, or at both points in the slaughter process, is presented as an alternative to moist heat. This process has the potential to be rapid and operational in an industrial setting which, when combined with water washing, could reduce APC, coliforms, *E. coli*, and pathogenic bacteria from beef carcass surfaces more effectively than water washing alone.

Materials and Methods

Beef shortplates, bovine feces, and inoculation procedures

Beef carcass shortplates were obtained within 15 min post-exsanguination from beef carcass sides processed at a local cow and bull slaughterhouse. Shortplates were removed from carcasses between the fifth and the thirteenth rib and about 25 cm from the vertebrae to within 10 cm of the midline. The *cutaneous trunci* muscle covered the surfaces of the shortplates. Individual shortplates were placed in plastic bags, stored in insulated carriers to prevent rapid cooling, and transported to the Roman L. Hruska US Meat Animal Research Center (MARC) and used within 2 h of slaughter (Dorsa et al. 1996a).

On each day of an experiment, feces were obtained from three cows fed a corn-silage ration. One hundred grams of each feces sample were obtained and mixed together with either 100 ml of sterile distilled water (Experiments 2, 5 and 6) or in physiological saline containing select bacterial organisms (Experiments 3 and 4).

Areas to be sampled on each shortplate were marked with edible ink using a sterile, cotton-tipped swab and a sterile stainless-steel, 25 cm^2 template before inoculation with bovine feces. Shortplates were inoculated with the feces by paint-brush inoculation on pre-marked areas and left undisturbed for 15 min (Experiments 2, 3, 4, 5, 6; Dorsa et al. 1996a). Samples that were desiccated prior to inoculation, were marked as above within 1 min of desiccation. All samples used in this study were obtained by excising the pre-marked 25 cm^2 area from the *cutaneous trunci* of the shortplates using sterile scalpels and forceps. Sample excision involved cutting all way through the muscle to the underlying tissues (*c.* 0·5 cm thick).

Desiccation procedures

Surface desiccation was performed using a Universal propane, forced-air heater (Model # 3500-FACV; Scheu Products, Co., Rancho Cucamonga, CA, USA.). A single desiccation procedure was performed by positioning the heater either 15 cm from the shortplate surface for 15 s to achieve a temperature of *c.* 400°C±5°C ($D_{15}^{400°C}$; Experiments 1, 2, 3 and 4) or 20 cm for 10, 12, or 15 s to obtain *c.* 300°C±5°C ($D_{10,12,15}^{300°C}$; Experiments 5, 6 and 7) at the tissue surface. The air temperature was monitored at the beef surface using an

OM-160 portable datalogger with type T Teflon™-coated thermocouples (Omega Engineering Co., Stamford, CT, USA.). For treatments in which two desiccation treatments were employed, the second desiccation treatment was applied immediately after the water wash. The heater was positioned either 15 cm from the shortplate for 30 s to achieve an air temperature of *c.* 400°C±5°C ($D^{400°C}$; Experiments 1, 2, 3 and 4) or positioned 20 cm from the shortplate for 15, 20, or 25 s to obtain an air temperature of *c.* 300°C±5°C ($D_{15,20,25}{}^{300°C}$; Experiments 6 and 7). The surface temperatures of the shortplates were determined immediately after the second desiccation procedure with a hand-held infrared non-contact thermometer (Omega).

Spray washing procedures

Spray washes with tap water were conducted in the model carcass washer (Experiments 1, 2, 5, 6 and 7) located at USMARC (Dorsa et al. 1996a) or with the insertable pod in a laminar air flow hood (Experiments 3 and 4; Dorsa et al. 1996b). The operation parameters for either washer were as follows: spray nozzle oscillation speed, 60 cycles/min; exposure to spray; 15 s; line pressure, 125 psi; flow rate, 4·8 l/min; temperature of spray at nozzle, 35°C±2°C (Model 40605 automatic 10 point temperature scanner, Davis Instruments, Inc., Baltimore, MD, U.S.A.).

Experimental design

Experiment 1 Four 25 cm^2 areas were marked on each shortplate as described above. Prior to any treatment, one 25 cm^2 area was excised from the shortplate for bacterial enumeration. Individual treatments were applied to separate shortplates as follows: water washed (W); desiccated ($D_{15}{}^{400°C}$); desiccated and water washed ($D_{15}{}^{400°C}$ W); or desiccated, water washed, and desiccated ($D_{15}{}^{400°C}$ $WD_{30}{}^{400°C}$). Immediately after any treatment, two 25 cm^2 areas were excised; one for bacterial enumeration, the other for moisture content analysis. The remaining area was left for moisture content analysis after 24 h, 5°C. Samples were analysed for APC, *E. coli* and coliform populations (see enumeration procedures).

Moisture content was determined by drying the excised 25 cm^2 areas in a 105°C± 5°C oven, 24 h (Wang et al. 1996). The following calculation was used to determine the percent (%) moisture content of the individual samples:

Weight of sample before drying—weight of sample after drying/weight of sample before drying=% moisture content

Experiment 2 One 25 cm^2 area was marked with edible ink on each shortplate prior to inoculation with feces as described above. Shortplates were treated as follows: untreated and inoculated with feces (UI); desiccated and inoculated ($D_{15}{}^{400°C}$ I); inoculated and water washed (IW); desiccated, inoculated, and water washed ($D_{15}{}^{400°C}$ IW); inoculated, water washed, and desiccated ($IWD_{30}{}^{400°C}$); and desiccated, inoculated, water washed, and desiccated ($D_{15}{}^{400°C}$ $IWD_{30}{}^{400°C}$). APC, *E. coli*, and coliform populations were enumerated as described below.

Experiment 3 Antibiotic-resistant *E. coli* O157:H7 Streptomycin^R, *Listeria innocua* Streptomycin^R, *Clostridium sporogenes* Novobiocin^R, and *Salmonella typhimurium* Nalidixic acid^R were obtained from USMARC culture collection and maintained in 75% glycerol at –20°C. *E. coli* O157:H7, *L. innocua*, and *S. typhimurium* were propagated by quiescent incubation in tryptic soy broth (TSB; Troy Biologicals, Troy, MI, U.S.A.) containing 250 μg/ml or 500 μg/ml of streptomycin sulfate (Sigma), or 250 μg/ml of nalidixic acid (Sigma), respectively, at 37°C, 18 h. *C. sporogenes* was propagated in thioglycollate broth (Difco) containing 50 μg/ml of novobiocin (Sigma) at 37°C, 36 h. All cultures were diluted in sterile physiological saline before inoculating into fresh bovine feces to obtain pathogen populations of *c.* 10^4 CFU/g and APC of 10^7 CFU/g.

One 25 cm^2 area was marked with edible ink on each shortplate, prior to inoculation

with feces containing the organisms of interest, as described in Experiment 1. Individual treatments were applied to separate shortplates as follows: untreated and inoculated (UI); desiccated and inoculated ($D_{15}^{400°C}$ I); inoculated and water washed (IW); desiccated, inoculated, and water washed ($D_{15}^{400°C}$ IW). APC and specific bacterial populations were enumerated as described below.

Experiment 4 Antibiotic-resistant bacteria were inoculated into bovine feces as described in Experiment 3. One 25 cm^2 area was marked on each shortplate as described previously. Individual treatments were applied to separate shortplates. The treatments were as follows: untreated and inoculated (UI); inoculated and water washed (IW); and desiccated, inoculated, water washed, and desiccated ($D_{15}^{400°C}$ $IWD_{30}^{400°C}$). APC and specific bacterial populations were enumerated as described below.

Experiment 5 In Experiments 3 and 4, visual assessments of shortplates were made immediately after treatments and after 24 h of refrigerated storage by three expert meat scientists. Based on the observations of these individuals, a modified desiccation procedure was devised for Experiments 5, 6, and 7. In this specific experiment, the heater was positioned 20 cm from the shortplate surface to obtain an air temperature of *c*. 300°C. One 25 cm^2 area was marked on each shortplate as described previously. The treatments were applied to separate shortplates as follows: untreated and inoculated (UI); inoculated and water washed (IW); desiccated for 10 s, inoculated, and water washed ($D_{10}^{300°C}$ IW); desiccated for 12 s, inoculated, and water washed ($D_{12}^{300°C}$ IW); and desiccated for 15 s, inoculated, and water washed ($D_{15}^{300°C}$ IW). APC, *E. coli*, and coliform populations were enumerated as described below.

Experiment 6 Based on the results in Experiment 5, beef surfaces were subjected to the first desiccation ($D_{10}^{300°C}$ IW) with the second desiccation step applied for different times (15, 20 or 25 s). One 25 cm^2 area was marked on each shortplate as described previously. The following treatments were applied to separate shortplates: untreated and inoculated (UI); inoculated and water washed (IW); desiccated, inoculated, water washed, and desiccated for 15 s ($D_{10}^{300°C}$ $IWD_{15}^{300°C}$); desiccated, inoculated, water washed, and desiccated for 20 s ($D_{10}^{300°C}$ $IWD_{20}^{300°C}$); and desiccated, inoculated, water washed, and desiccated for 25 s ($D_{10}^{300°C}$ $IWD_{25}^{300°C}$). APC, *E. coli*, and coliform populations were enumerated as described below.

Experiment 7 Using the best treatments in Experiments 5 and 6 ($D_{10}^{300°C}$ $IWD_{25}^{300°C}$), another experiment was performed on un-inoculated shortplates. For this experiment, four 25 cm^2 areas were marked on each shortplate as described previously. Prior to the treatment, one 25 cm^2 area was excised from the shortplate for bacterial enumeration (untreated, U) and moisture content. The other treatments were applied to separate shortplates as follows: water washed (W); desiccated, water washed, and desiccated ($D_{10}^{300°C}$ W $D_{25}^{300°C}$). Immediately after either treatment, two 25 cm^2 areas were excised, one for bacterial enumeration and the other for moisture content analysis. The remaining 25 cm^2 area was analysed for moisture content after 24 h, 5°C (see Experiment 1). Color was assessed visually on samples immediately after the treatments and again after 24 h, 5°C. APC, *E. coli*, and coliform populations were enumerated as described below.

Bacterial enumeration

Each excised 25 cm^2 piece was pummeled (Model 400 Stomacher, Tekmar, Cincinnati, OH, USA) for 2 min in 25 ml of a stomaching buffer (BPW, Difco, Detroit, MI; 0·1% Tween 20, Fisher Scientific Co., St. Louis, MO, USA). All serial dilutions were made in BPW. Samples from Experiments 1, 3, 4, 5, and 6, were plated on trypticase soy agar (TSA, BBL, Cockeysville, MD, USA) for aerobic plate counts (APC) using a Model D Spiral Plater (Spiral Biotech, Bethesda, MD, USA)

or by spread plating. Samples from these experiments also were plated onto *E. coli* petrifilm (3M, Inc., St. Paul, MN) for *E. coli* and coliforms, according to the manufacturer's instructions. Samples from Experiments 2 and 7 were plated onto APC Petrifilm (3M, Inc.) and *E. coli* Petrifilm for *E. coli* and coliforms. Samples from Experiments 3 and 4 were spiral or spread plated (250 µl; in quadruplicate) onto the following media: TSA for APC; sorbitol McConkey agar (SMAC, Difco) containing 250 µg/ml of streptomycin sulfate for isolation of *E. coli* O157:H7; Oxoid Listeriae Selective agar (LSA, Unipath, Ogdensburg, NY, USA) containing 500 µg/ml of streptomycin sulfate for isolation of *L. innocua*; Clostridium Botulinum Isolation agar without egg yolk (CBI; Silas et al. 1985) containing 50 µg/ml of novobiocin for isolation of *C. sporogenes*; and Brilliant Green Sulfite agar (BGS, Difco) containing 250 µg/ml of nalidixic acid for isolation of *S. typhimurium*. The lowest level of detection of APC or pathogen was 1·30 $\log_{10}$ CFU/cm^2 using spiral plating procedures; samples that were spread plated in quadruplicate were used to detect total number of CFU/cm^2. Plates from all experiments were enumerated after incubation at 35°C for 48 h.

Calculations and statistical analyses

From plate count data, remaining populations were determined from each treatment and for each experiment. Populations were converted to $\log_{10}$ CFU/cm^2 prior to analyses. Least square means (LSM) of bacterial populations were calculated from six experimental replications, unless otherwise noted, and subjected to the General Linear Models procedure of SAS (Cary, NC) for statistical analyses (Experiments 2, 3, 4, 5 and 6). The probability level was $P \leqq 0{\cdot}05$, unless otherwise noted.

Results

Experiment 1

Desiccation of the shortplate surface before ($D_{15}^{400°C}$ W) and after water washing ($D_{15}^{400°C}$ $WD_{30}^{400°C}$) reduced APC from un-inoculated shortplates to a greater extent than W or $D_{15}^{400°C}$ alone (Table 1). Bacterial populations were undetectable following $D_{15}^{400°C}$ $WD_{30}^{400°C}$, while <1 $\log_{10}$ CFU/cm^2 was detected with the other treatments. Conversely, populations of coliforms and *E. coli* were reduced to undetectable levels regardless of the treatment applied.

The moisture content of samples taken from treated shortplates was determined (Table 2). This information indicates that the samples subjected to $D_{15}^{400°C}$ $WD_{30}^{400°C}$ at day 0 had 7% less moisture than U and W samples. After 24 h under refrigeration, the moisture content from all samples decreased. Samples subjected to $D_{15}^{400°C}$ $WD_{30}^{400°C}$ had a moisture content of 68% which was 8% less moisture than W samples, but only 1% less than U samples.

Table 1. Experiment 1. Bacterial populations remaining on un-inoculated beef shortplates before and after desiccation, water washing, or combination procedures. The numbers presented represent the mean of six replications

Treatment*	APC $\log_{10}$ CFU/cm^2		Coliforms $\log_{10}$ CFU/cm^2		*E. coli* $\log_{10}$ CFU/cm^2	
	Before	After	Before	After	Before	After
W	1·42^a	0·81^a	0·39^a	u/d^a	0·32^a	u/d^a
$D_{15}^{400°C}$	1·67^a	0·62^a	0·37^a	u/d^a	0·06^a	u/d^a
$D_{15}^{400°C}$ W	1·17^{ab}	0·03^a	0·08^a	u/d^a	u/d^a	u/d^a
$D_{15}^{400°C}$ $WD_{30}^{400°C}$	0·55^b	u/d^a	0·00^a	u/d^a	u/d^a	u/d^a

*W=water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$=desiccation, 400°C, 15 s.
$D_{15}^{400°C}$ W=desiccation, 400°C, 15 s, water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$ $WD_{30}^{400°C}$=desiccation, 400°C, 15 s, water wash (125 psi, 35°C, 15 s), desiccation 400°C, 30 s.
$^{a, ab, b}$Denote statistical differences between treatments within columns ($P \leqq 0{\cdot}05$).
u/d=detectable (<1 CFU/cm^2).

Visual observation of the shortplate surface immediately after the various treatments indicated that the initial desiccation step resulted in discoloration of the meat surfaces; however, after 24 h of refrigerated storage only a slight, but noticeable discoloration remained.

Table 2. Experiment 1. Moisture content of samples from un-inoculated beef shortplates before and after desiccation, water wash, or combination procedures at day 0 and after 24 h, 4°C. The numbers presented represent the mean of six replications

Treatment*	Average moisture content (%)	
	Day 0	After 24 h, 4°C
U	78[a]	69[b]
W	78[a]	76[a]
$D_{15}^{400°C}$	75[ab]	72[ab]
$D_{15}^{400°C}$ W	76[ab]	75[a]
$D_{15}^{400°C}$ $WD_{30}^{400°C}$	71[b]	68[b]

*U=Untreated.
W=water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$=desiccation, 400°C, 15 s.
$D_{15}^{400°C}$ W=desiccation, 400°C, 15 s, water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$ $WD_{30}^{400°C}$=desiccation, 400°C, 15 s, water wash (125 psi, 35°C, 15 s), desiccation 400°C, 30 s.
[a, ab, b]Denote statistical differences between treatments within columns ($P \leqq 0{\cdot}05$).

Experiment 2

Any combination of desiccation and washing reduced populations of APC, coliforms, and *E. coli* associated with fecal contamination better than IW samples (Table 3). While IW reduced fecal APC to 4·38 $\log_{10}$ CFU/cm^2, $D_{15}^{400°C}$ IW and $IWD_{30}^{400°C}$ reduced fecal APC to 3·70 and 3·20 $\log_{10}$ CFU/cm^2, respectively. Of the various combinations examined in this experiment, $D_{15}^{400°C}$ $IWD_{30}^{400°C}$ reduced APC to the greatest extent (2·50 $\log_{10}$ CFU/cm^2). Both coliforms and *E. coli* were reduced to nearly undetectable levels following $D_{15}^{400°C}$ $IWD_{30}^{400°C}$, while bacterial populations of >1 $\log_{10}$ CFU/cm^2 were demonstrated following all the other treatments.

After treatments, visible fecal contamination was observed on all UI and DI samples, while some staining was observed on IW and $IWD_{30}^{400°C}$ samples. No contamination or staining was observed on $D_{15}^{400°C}$ IW samples or samples treated with $D_{15}^{400°C}$ $IWD_{30}^{400°C}$.

Experiment 3

Residual APC of $D_{15}^{400°C}$ IW samples were significantly lower (3·86 $\log_{10}$ CFU/cm^2) than IW samples (4·05 $\log_{10}$ CFU/cm^2) (Table 4). Specific bacterial populations of *L. innocua*, *C. sporogenes*, *S. typhimurium*, were reduced to undetectable levels; *E. coli* O157:H7 was

Table 3. Experiment 2. Bacterial populations remaining on fecally contaminated beef shortplates following desiccation, water wash, or combination procedures

Treatment*	APC** $\log_{10}$ CFU/cm^2	Coliforms*** $\log_{10}$ CFU/cm^2	*E. coli**** $\log_{10}$ CFU/cm^2
UI	6·45[a]	5·14[a]	4·87[a]
$D_{15}^{400°C}$ I	6·23[a]	5·27[a]	5·04[a]
IW	4·38[b]	3·51[b]	1·99[b]
$D_{15}^{400°C}$ IW	3·70[c]	2·98[c]	1·76[b]
$IWD_{30}^{400°C}$	3·20[d]	1·66[d]	1·07[c]
$D_{15}^{400°C}$ $IWD_{30}^{400°C}$	2·50[e]	0·49[e]	0·17[d]

*UI=untreated, inoculation with bovine feces.
**The numbers presented represent the mean of 12 replications
***The numbers presented represent the mean of six replications.
$D_{15}^{400°C}$ I=desiccation, 400°C, 15 s, inoculation with bovine feces.
IW=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$ IW=desiccation, 400°C, 15 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$IWD_{30}^{400°C}$=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s), desiccation 400°C, 30 s.
$D_{15}^{400°C}$ $IWD_{30}^{400°C}$=desiccation, 400°C, 15 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s), desiccation 400°C, 30 s.
[a–e]Denotes significant differences between treatments within columns ($P \leqq 0{\cdot}05$).

reduced to 0·68 $\log_{10}$ CFU/cm^2 with $D_{15}^{400°C}$ IW. IW did reduce *S. typhimurium* to undetectable levels; however, populations of *L. innocua*, *C. sporogenes*, and *E. coli* O157:H7 were reduced only to 0·38, 0·58, and 1·22 $\log_{10}$ DFU/cm^2, respectively.

Experiment 4

As was observed with Experiment 2, $D_{15}^{400°C}$ $IWD_{30}^{400°C}$ reduced bacterial populations on shortplate surfaces to a greater extent than IW (Table 5). Specifically, APC of 3·99 $\log_{10}$ CFU/cm^2 were observed following IW; APC of 3·25 $\log_{10}$ CFU/cm^2 were observed following $D_{15}^{400°C}$ $IWD_{30}^{400°C}$. While IW did not reduce *L. innocua*, *C. sporogenes*, *S. typhimurium*, or *E. coli* O157:H7 to undetectable levels, $D_{15}^{400°C}$ $IWD_{30}^{400°C}$ did.

Experiment 5

Experiment 5 was conducted to test modifications to the desiccation procedure in order to reduce the discoloration effects observed in Experiments 1 through 4. To improve the appearance of shortplates after the desiccation steps and to shorten the time required for desiccation procedures, the heater was positioned 20 cm (instead of 15 cm) from the shortplate to obtain an air temperature of *c.* 300°C. This desiccation procedure was applied to un-inoculated shortplates for 10, 12, or 15 s and then subjected to a water wash ($D_{10}^{300°C}$ W; $D_{12}^{300°C}$ W; $D_{15}^{300°C}$ W). APC for $D_{10}^{300°C}$ W, $D_{12}^{300°C}$ W, and $D_{15}^{300°C}$ W samples were 2·48, 2·36 and 2·26 $\log_{10}$ CFU/cm^2, respectively, whereas APC following W were 3·22 $\log_{10}$ CFU/cm^2 (Table 6). Vis-

Table 4. Experiment 3. Bacterial populations remaining on fecally contaminated beef shortplates following desiccation, water washing, or combination procedures. The numbers presented represent the mean of six replications

Treatment*	APC** $\log_{10}$ CFU/cm^2	*L. innocua* $\log_{10}$ CFU/cm^2	*C. sporogenes* $\log_{10}$ CFU/cm^2	*S. typhimurium* $\log_{10}$ CFU/cm^2	*E. coli* O157:H7 $\log_{10}$ CFU/cm^2
UI	6·41^a	3·88^a	4·40^a	n/d**	3·33^a
$D_{15}^{400°C}$ I	6·02^b	3·79^a	4·24^a	3·40^a	3·11^b
IW	4·05^b	0·38^b	0·58^b	u/d^b	1·22^c
$D_{15}^{400°C}$ IW	3·86^c	u/d^c	0·03^c	u/d^b	0·68^d

*UI=untreated, inoculation with bovine feces.
$D_{15}^{400°C}$ I=desiccation, 400°C, 15 s, inoculation with bovine feces.
IW=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$ IW=desiccation, 400°C, 15 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
**n/d=not determined.
$^{a–d}$Denotes significant differences between treatments within columns ($P \leqq 0·05$).
u/d=undetectable (<1 CFU/cm^2).

Table 5. Experiment 4. Bacterial populations remaining on fecally contaminated beef shortplates following desiccation, water washing, or combination procedures. The numbers presented represent the mean of six replications

Treatment*	APC $\log_{10}$ CFU/cm^2	*L. innocua* $\log_{10}$ CFU/cm^2	*C. sporogenes* $\log_{10}$ CFU/cm^2	*S. typhimurium* $\log_{10}$ CFU/cm^2	*E. coli* O157:H7 $\log_{10}$ CFU/cm^2
UI	6·46^a	3·97^a	3·63^a	2·61^a	3·30^a
IW	3·99^b	1·23^b	0·65^b	0·32^b	0·48^b
$D_{15}^{400°C}$ $IWD_{30}^{400°C}$	3·25^c	u/d^c	u/d^c	u/d^c	u/d^c

*UI=untreated, inoculation with bovine feces.
IW=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{15}^{400°C}$ $IWD_{30}^{400°C}$=desiccation, 400°C, 15 s, inoculation with bovine feces, water wash. (125 psi, 35°C, 15 s), desiccation, 400°C, 30 s.
$^{a–c}$Denotes significant differences between treatment within columns ($P \leqq 0·05$).
u/d=undetectable (<1 CFU/cm^2).

ual observation immediately after treatments indicated that $D_{10}^{300°C}$ W, $D_{12}^{300°C}$ W, or $D_{15}^{300°C}$ W exhibited an appearance similar to IW.

Experiment 6

To minimize the discoloration associated with $D_{15}^{400°C}$ $WD_{30}^{400°C}$, the second desiccation procedure was modified. Immediately after washing, the heater was positioned 20 cm from the shortplate to obtain an air temperature of *c.* 300°C and applied for 15, 20, or 25 s ($D_{10}^{300°C}$ $WD_{15}^{300°C}$; $D_{10}^{300°C}$ $WD_{20}^{300°C}$; $D_{10}^{300°C}$ $WD_{25}^{300°C}$). Using this modified procedure, residual APC of 3·34, 2·74, and 2·55 $\log_{10}$ CFU/cm^2 were detected for $D_{10}^{300°C}$ $WD_{15}^{300°C}$, $D_{10}^{300°C}$ $WD_{20}^{300°C}$, and $D_{10}^{300°C}$ $WD_{25}^{300°C}$, respectively (Table 7). Water washing (W) alone resulted in APC of 3·78 $\log_{10}$ CFU/cm^2. Similarly, coliform populations of 2·07, 1·69, 1·42, and 0·88 $\log_{10}$ CFU/cm^2 were observed for shortplates subjected to water washes, $D_{10}^{300°C}$ $WD_{15}^{300°C}$, $D_{10}^{300°C}$ $WD_{20}^{300°C}$, and $D_{10}^{300°C}$ $WD_{25}^{300°C}$, respectively. Of the desiccation treatments examined, only $D_{10}^{300°C}$ $WD_{25}^{300°C}$ significantly reduced populations of *E. coli* below those obtained with IW.

Table 6. Experiment 5. Bacterial populations remaining on fecally contaminated beef shortplates following desiccation, water washing, or combination procedures. The numbers presented represent the mean of six replications

Treatment*	APC $\log_{10}$ CFU/cm^2
UI	6·14[a]
IW	3·22[b]
$D_{10}^{300°C}$ IW	2·48[c]
$D_{12}^{300°C}$ IW	2·36[c]
$D_{15}^{300°C}$ IW	2·26[c]

*UI=untreated, inoculation with bovine feces.
IW=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{10}^{300°C}$ IW=desiccation, 300°C, 10 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{12}^{300°C}$ IW=desiccation, 300°C, 12 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{15}^{300°C}$ IW=desiccation, 300°C, 15 s, inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
[a–c]Denote statistical differences between treatments within column ($P \leqq 0{\cdot}05$).

Experiment 7

On un-inoculated shortplates, APC were significantly reduced and coliforms and *E. coli* were reduced to undetectable levels by $D_{10}^{300°C}$ $WD_{25}^{300°C}$, as compared to W alone (Fig. 1). Analyses of moisture content from samples treated with W or $D_{10}^{300°C}$ $WD_{25}^{300°C}$ indicated no statistical differences between the two treatments on either day (Table 8). Visual observations indicated that shortplates from $D_{10}^{300°C}$ $WD_{25}^{300°C}$ treatments were similar in appearance to IW immediately after treatments and again after 24 h of refrigerated storage.

Table 7. Experiment 6. Bacterial populations remaining on fecally contaminated beef shortplates following desiccation, water washing, or combination procedures. The numbers presented represent the mean of six replications

Treatment*	APC $\log_{10}$ CFU/cm^2	Coliforms $\log_{10}$ CFU/cm^2	*E. coli* $\log_{10}$ CFU/cm^2
UI	6·31[a]	5·04[a]	4·65[a]
IW	3·78[b]	2·07[b]	1·61[b]
$D_{10}^{300°C}$ $IWD_{15}^{300°C}$	3·34[c]	1·69[bc]	1·46[b]
$D_{10}^{300°C}$ $IWD_{20}^{300°C}$	2·74[d]	1·42[c]	1·25[b]
$D_{10}^{300°C}$ $IWD_{25}^{300°C}$	2·55[d]	0·88[d]	0·42[c]

*UI=untreated, inoculation with bovine feces.
IW=inoculation with bovine feces, water wash (125 psi, 35°C, 15 s).
$D_{10}^{300°C}$ $IWD_{15}^{300°C}$=desiccation, 300°C, 10 s, inoculation with bovine feces, water wash. (125 psi, 35°C, 15 s), desiccation, 300°C, 15 s.
$D_{10}^{300°C}$ $IWD_{20}^{300°C}$=desiccation, 300°C, 10 s, inoculation with bovine feces, water wash. (125 psi, 35°C, 15 s), desiccation, 300°C, 20 s.
$D_{10}^{300°C}$ $IWD_{25}^{300°C}$=desiccation, 300°C, 10 s, inoculation with bovine feces, water wash. (125 psi, 35°C, 15 s), desiccation, 300°C, 25 s.
[a–d]Denote statistical differences between treatments within columns ($P \leqq 0{\cdot}05$).

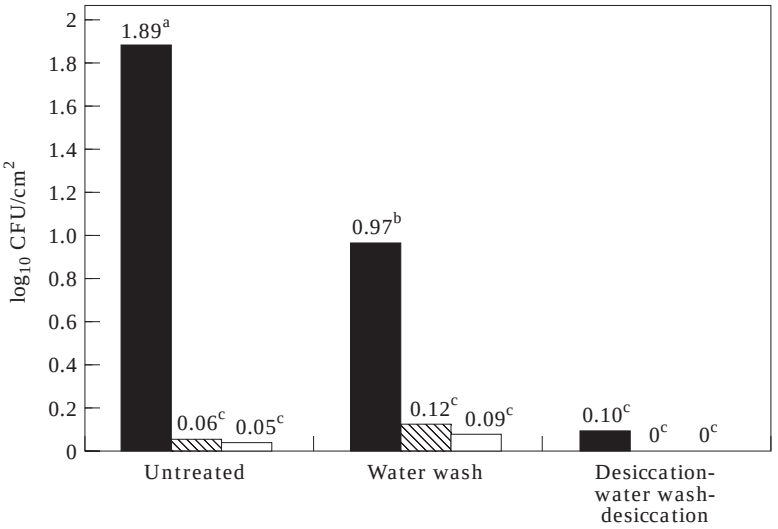

Figure 1. Effect of water wash or desiccation ($D_{10}^{300°C}$ $WD_{25}^{300°C}$) for removal of APC (■) coliforms (▨) or *E. coli* (□) from un-inoculated shortplates. [a,b,c]Denote statistical significance between treatments involving APC ($P \leqq 0{\cdot}05$). (n=12 for all treatments, except for untreated where n=24).

Discussion

In this study, it has been demonstrated that using rapid desiccation with dry heat before inoculation and after water washing (Experiment 2) was more effective than water washing for the immediate reduction of bacterial populations on beef surfaces. Both desiccation steps, together with water washes, afford the greatest reductions of bacteria observed in these studies. The use of desiccation on the carcass surface at two points in slaughter process (before contamination and after water washing) could serve two functions. First, desiccation before inoculation appears to dehydrate the carcass surface and possibly shrinking the connective tissue components on the carcass surface. Shrinkage and possible dehydration may affect how bacteria attach to the carcass surface and ultimately, their removal during water washes. Second, desiccation after water washing produces a moist heat intervention since water found on the carcass surface becomes heated to >65°C.

The effects of desiccation on inoculated beef surfaces were also investigated in preliminary studies. When feces containing *E. coli* O157:H7 were inoculated onto beef carcass tissue, desiccated (85°C, 3 min) using a hand-held heat gun (Varitemp; Model #VT-7508; Master Appliance Corporation, Racine, WI) and water washed, populations of the pathogen were reduced to levels comparable to surfaces only inoculated and water washed (unpublished data). Under these conditions, it appeared that heat generated from desiccation procedures was detrimental to the pathogen and that subsequent water washes assisted in the removal of the pathogen from beef carcass surfaces (unpublished data).

Table 8. Experiment 7. Moisture content of samples from un-inoculated beef shortplates before and after desiccation, water wash, or combination procedures at day 0 and after 24 h, 4°C. The numbers presented represent the mean of 12 replications

Treatment*	Average moisture content (%)	
	Day 0	After 24 h, 4°C
U	73[a]	n/d**
W	77[b]	71[a]
$D_{10}^{300°C}$ $WD_{25}^{300°C}$	76[b]	73[a]

*U=untreated.
W=water wash (125 psi, 35°C, 15 s).
$D_{10}^{300°C}$ $WD_{25}^{300°C}$=desiccation, 300°C, 10 s, inoculation with bovine feces, water wash. (125 psi, 35°C, 15 s), desiccation, 300°C, 25 s.
**n/d=not determined.
[a,b]Denote statistical differences between treatments within columns.

In this study, the effects of desiccation and water washing on beef carcass shortplates were performed using the lean tissue from the *cutaneous trunci*. Research conducted to compare the effect of tissue types with other interventions has indicated that bacteria are removed to a greater extent on adipose than on lean tissue (Cutter and Siragusa 1994). The effects of desiccation and water washes for removal of APC and *E. coli* O157:H7 on adipose tissues have been investigated. Preliminary studies using pre-rigor adipose tissue and a hand-held heat gun (Varitemp) found that bacteria were removed more effectively than by water washes alone if desiccation (145°C, 2 min) was performed prior to inoculation and followed by a water wash (unpublished data). Under these conditions, the adipose surface appeared to liquify such that the fecal inoculum actually did not adhere to the tissue surface and remaining feces were removed during water washes (unpublished data). Since the surfaces of beef carcasses are composed primarily of adipose tissue, it would appear that desiccation and spray washing should remove bacteria more effectively from adipose surfaces. Additional studies are underway to determine the effects of desiccation and other interventions on both lean and predominantly adipose surfaces from beef carcasses.

It has been previously reported that the application of moist heat may actually result in hydration of the carcass surface (Thomas and McMeekin 1982, Dorsa et al. 1996b). It also is believed that hydration not only expands surface components, such as collagen, but also may increase the surface area, allowing bacteria to attach more readily (Rodrigues-Szulc et al. 1996). It is speculated that shrinking occurs during desiccation, thereby causing a decrease in the surface area to which bacteria can attach during inoculation procedures.

Dickson (1990) demonstrated that a combination of osmotic stress of bacterial cells, dehydration of the meat surface in a cooler, and acetic acid washes were effective for reducing pathogens on beef surfaces. In that study, *S. typhimurium* and *L. monocytogenes* were attached to beef tissue, allowed to dehydrate at 5°C for up to 6 hours, washed with 2% acetic acid or phosphate buffer, and remaining bacterial populations enumerated. It was hypothesized that osmotic stress and dehydration affected the bacterial cell such that acetic acid washes effectively reduced the pathogens.

Moist heat application significantly reduces bacterial populations on un-inoculated and fecally-contaminated beef surfaces (Barkate et al. 1993, Dorsa et al. 1996a, 1996b, Nutsch et al. 1997). In the present study, temperature surveys of samples taken from beef surfaces immediately after the water wash averaged 35°C (data not presented). Immediately following the water wash, temperature surveys following hot air desiccation ($D_{10,12,15}^{300°C}$ or $D_{30}^{400°C}$) indicated a rise in the carcass surface temperature to an average of 65 and 70°C, respectively (data not presented). Temperatures >65°C are sufficient to reduce bacterial populations on beef surfaces (Dorsa et al. 1996b). Based on the results from the present study (Experiment 2), it is speculated that desiccation immediately after water washing generates sufficient dry and moist heat to reduce bacteria remaining on the carcass surface. While heat injured cells may be present following the second desiccation procedure, this study did not attempt to identify those populations. Earlier research conducted with some of the antibiotic resistant organisms used in this study (Dorsa et al. 1997) indicates that heat treatments may only suppress the organisms temporarily. Bacteria treated with steam or hot water treatments did grow under vacuum packaged, refrigerated storage up to 21 days; however the populations did not grow to initial or control levels (Dorsa et al. 1997).

Modification of both desiccation processes to 300°C not only minimized discoloration as compared to 400°C, but also decreased moisture loss without reducing the effectiveness of the desiccation process. Also, the shorter desiccation times may be more adaptable to an industrial slaughter process.

Conclusions

It is possible a non-hydrating intervention, such as desiccation, could provide a means of

minimizing hydration, collagen expansion, and possibly bacterial attachment during the slaughter process, especially when used prior to fecal contamination. Immediately after water washes, desiccation also could provide a rapid and an economical means of generating both dry and moist heat in order to destroy bacteria remaining on the carcass surface. Based on this study and under the conditions described, hot air desiccation, when combined with water washes, is more effective than water washes alone for reducing undesirable bacteria on beef carcass surfaces.

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