DEATH OF *SALMONELLA* SEROVARS, *ESCHERICHIA COLI* O157 : H7, *STAPHYLOCOCCUS AUREUS* AND *LISTERIA MONOCYTOGENES* DURING THE DRYING OF MEAT: A CASE STUDY USING BILTONG AND DROËWORS

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ABSTRACT

Biltong and droëwors are ready-to-eat dried seasoned beef strips and sausages, respectively. Procedures to meet process lethality requirements for these products have not been validated. The fate of Salmonella *serovars,* Escherichia coli *O157 : H7,* Staphylococcus aureus*, and* Listeria monocytogenes *was evaluated during the manufacture and vacuum-packaged storage (7 days at 20–22C) of three lots each of biltong and droëwors. Acid-adapted pathogens were used as inocula (ca. 7 log CFU per sample for each pathogen). The biltong manufacturing process reduced pathogen levels from 1.2 to 3.8 log CFU (*S. aureus *and* L. monocytogenes*, respectively). Less lethality was achieved in making droëwors, probably because of the higher fat content. The manufacturing processes for biltong and droëwors achieved significant lethality. Combined with additional intervention steps and/or raw material testing, the processes would achieve mandated levels of pathogen destruction.*

PRACTICAL APPLICATIONS

The results of our experimental trials can be applied to commercial dried meat products with water activity, MPR, pH and % water-phase salt at least as

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restrictive as our trial products. It was clear from our results that drying of seasoned beef strips or sausage would result in significant reduction in numbers for all four pathogens tested.

INTRODUCTION

Drying is used in making a variety of specialty processed meats. Drying procedures vary in terms of temperature, relative humidity, rate of air movement, and final product characteristics. Some products are dried at ambient temperatures, e.g., country ham, and others, such as beef jerky, are dried at elevated temperatures (Aberle *et al.* 2001). Biltong and droëwors are two shelf-stable ready-to-eat dried beef products developed in South Africa. Traditionally these products were made by drying meat under ambient conditions. To make biltong, beef strips are seasoned (high-salt) and dried. To make droëwors, small pieces of beef are obtained from trimming and/or grinding, seasoned (high-salt), stuffed into casings, and dried. In essence, these two products could be viewed as very thick versions of whole-muscle and ground-and-formed beef jerky, made without elevated heat. Both biltong and droëwors are currently made in the U.S.A. The United States Department of Agriculture (USDA) currently requires processes used in making ready-to-eat beef products to achieve a 6.5 log reduction of *Salmonella* serovars (USDA Food Safety and Inspection Service 1999a). Guidance exists for achieving such a reduction using thermal processes (USDA Food Safety and Inspection Service 1999b) but little is known about whether this level of lethality can be achieved using ambient-temperature drying processes. An additional microbial standard that may be relevant to biltong and droëwors is a $\geq$ 5-log reduction in *E. coli* O157 : H7 in dry and semi-dry fermented beef products (USDA Food Safety and Inspection Service 2005a). An alternative standard for these products is that a process may be considered safe if it achieves a $\geq$2-log reduction of *E. coli* O157 : H7 and if the sausage mix before drying contains $\leq$1 *E. coli* O157 : H7 CFU/g (USDA Food Safety and Inspection Service 2005a). Recent information from the USDA (UHLER 2005) has also indicated that a 5-log reduction in *Salmonella* serovars during the manufacture of a shelf-stable beef product would be an acceptable standard because adoption of this standard, in place of the 6.5-log reduction standard for cooked products, is very unlikely to have any effect on the incidence of salmonellosis (USDA Food Safety and Inspection Service 2005b). Little has been reported on the survival of *Salmonella* serovars and *E. coli* O157 : H7 during the manufacture of biltong and droëwors, so the first objective of this study was to determine the extent to which these pathogens died during the manufacturing process.

Two other potentially significant microbiological hazards in biltong and droëwors are *Staphylococcus aureus* and *Listeria monocytogenes*. There is a

concern that *S. aureus*, being very tolerant of salt and reduced a_w, could outgrow indigenous bacteria during the manufacture of biltong and droëwors and produce heat-stable enterotoxin. *Listeria monocytogenes* is also very salt-tolerant and has a low infective dose for susceptible persons. Thus, there is concern over the growth and subsequent survival of *L. monocytogenes* in products that are not subjected to a thermal lethality step. Because the a_w of finished biltong and droëwors is typically 0.60–0.65, it is unlikely that either of these pathogens will grow on the finished products. Under aerobic conditions, *S. aureus* will not grow at an a_w of $\leq$0.85 (Jay 1992) and under anaerobic conditions the minimum a_w for growth of this organism is $\leq$0.88 (ICMSF 1996). The minimum a_w for *L. monocytogenes* growth is 0.92 (USDA Food Safety and Inspection Service 2004). However, it is not clear whether *S. aureus* or *L. monocytogenes* could grow during biltong and droëwors processing steps before the water activity fell below the minimum levels required for growth. Therefore, the second objective of our study was to evaluate the death, survival, and/or growth of *S. aureus* and *L. monocytogenes* during the biltong and droëwors manufacturing process.

MATERIALS AND METHODS

Inoculum Preparation

Five strains each of *Salmonella* serovars, *E. coli 0157 : H7*, *Staphylococcus aureus*, and *Listeria monocytogenes* were used for inoculation. *Salmonella* serovars used were *S.* Hadar S21, *S.* Typhimurium S9, *S.* Infantis S20, *S.* Anatum S14 and *S.* Heidelberg S13. All of the salmonellae were obtained from Dr. Eric Johnson (Food Research Institute, University of Wisconsin-Madison). The original source was unknown for strains S21 and S20, while strains S9, S13 and S14 were originally isolated from samples submitted to the Wisconsin State Laboratory of Hygiene. *E. coli* O157 : H7 strains ATCC 43894, 51657, and 51658 are clinical isolates, strain ATCC 43895 was from ground beef implicated in an outbreak (American Type Culture Collection, Manassas, VA). Strain USDA-FSIS-380-94 was originally isolated from salami linked to an illness outbreak and was obtained from Dr. John Luchansky (then at the Food Research Institute, University of Wisconsin-Madison). Two strains of *Staphylococcus aureus*, ATCC 12600 and 25923, were clinical isolates, with the former isolated from pleural fluid (American Type Culture Collection, Manassas, VA). Strains FRI 1007, 100 and 472, obtained from Dr. Amy Wong (Food Research Institute, University of Wisconsin-Madison), were from illness outbreaks associated with Genoa sausage, cake, and turkey salad respectively. The *L. monocytogenes* strains used were all obtained from the laboratory of Dr.

Eric Johnson (Food Research Institute, University of Wisconsin-Madison) and were originally from an infected patient (Scott A), hard salami (101 and 108), goat cheese (310) and raw milk (V7). Stock cultures were maintained at –20C in brain heart infusion broth (BHIB; Difco, Becton-Dickinson, Sparks, MD), with 10% (v/v) added glycerol (Fisher Scientific, Itasca, IL). Working cultures, maintained at 5C on brain heart infusion agar (BHIA; Difco) were prepared monthly from frozen stock cultures. To obtain a working culture, a strain was cultured twice successively at 35C for 18–24 h in BHIB, streaked to a BHIA plate, incubated at 35C for 18–24 h and examined for typical and homogeneous colony morphology, and then stored at 5C. To acid-adapt the pathogens, inoculation cultures were prepared for each strain by transferring a colony of growth from the working culture plate to ~9.2 mL of tryptic soy broth (Difco) with 1% (w/v) added glucose and incubating at 35C for 18–24 h. An inoculum was prepared for each pathogen by combining each of the five cultured strains into a 50-mL centrifuge tube (Falcon Brand, Fisher Scientific) and centrifuging at $5{,}000 \times g$ for 12 min. Supernatant was decanted and the pellet re-suspended to 22.5 mL using Butterfield's phosphate diluent (BPD; Nelson Jameson, Marshfield, WI). Separate five-strain, single-pathogen inocula were prepared for *S. aureus* and *L. monocytogenes*. From the two separate (five-strain) pathogen cocktails of *E. coli 0157 : H7* and *Salmonella* serovars, 10 mL of each were then combined into another 50-mL centrifuge tube, creating a ten-strain, two-pathogen inoculum.

Meat Fabrication and Inoculation

In each of three trials, fresh vacuum-packaged, commercial beef bottom round (flat), subprimal cuts were obtained from a local processor and stored at 5C until used ($\leq$7 days). The sub-primal cuts were trimmed of external fat and the ends squared off to produce a uniform shape. Prior to further fabrication the trimmed sub-primal cuts and all of the trimmings were liberally sprayed with a 0.13% (v/v) peracetic acid solution (Enviro Tech Chemical Services, Modesto, CA) and allowed to sit for 2 min. To make biltong, the trimmed sub-primal cuts were sliced on the cross-section using a commercial deli slicer (model 919E, Berkel Co., Denver, CO) to approximately 2.5 cm thickness. To inoculate each of 12 biltong strips with a given inoculum, a 0.3-mL volume of the undiluted inoculum (ca. log 9 CFU/mL) was pipetted onto one side of each strip surface and distributed evenly over the entire side using a sterile bent plastic spreader. With minor exceptions, the inoculum volume was sufficient to cover the surface area of the strip. The inoculated slices were allowed to sit for 30 min to aid microbial attachment; then each strip was turned over and the process repeated. Nine of the 12 (all 12 for the controls) strips for each inoculum were then placed into a double layer of vacuum-packaging bags and

proprietary amounts of vinegar and spice blend added; the bags were then heat-sealed and tumbled in a small table-top tumbler (Flavor Maker F15, Doug Care Equipment, Inc., Springville, CA) for 30 min. To make droëwors, trimmings were ground twice using a commercial meat grinder (Model 5323, Toledo Co., Toledo, OH), first through a plate with ~10 mm size holes and then through a plate with ~4 mm size holes. Four vacuum-packaging bags (one control and one for each of the three inoculum types) were each filled with about 3.6 kg of the ground meat and proprietary amounts of vinegar and spice blend were added. To inoculate the droëwors mix, a 10-mL volume of the undiluted inoculum (ca. log 9 CFU/mL) was added to the mixture and manually massaged for 10 min. Each bag of inoculated prepared droëwors mix was then stuffed into natural lamb casings. Both the biltong and droëwors were then hung on racks in an environmental chamber set at 22.2C (actual range 20–22C) with a target of 50% relative humidity (RH; actual range of 38–64%) for a period ranging from 12–21 days for droëwors and 17–26 days for biltong. Periodic measurements of water activity (a_w) were made on uninoculated biltong and droëwors. When a product's a_w had fallen to approximately 0.60, three strips or sausages per inoculum were separately vacuum-packaged and stored at 20–22C for 7 days.

Proximate Analyses

In all three trials, finished uninoculated biltong and droëwors samples were sent to a commercial testing laboratory for pH, water activity, % moisture (forced air oven method, AOAC method 950.46Bb), % protein (Kjeldahl method, AOAC method 991.20.I) and % salt (potentiometric method, AOAC method 980.25) analyses. From these analyses, moisture : protein ratio (MPR), and % water-phase salt values were calculated (Table 1). One commercial sample each of biltong and droëwors were also analyzed. In addition, samples from trial 3 were also analyzed for % fat (Soxhelet, AOAC method 960.39).

Enumeration of Surviving Cells

Samples were obtained after inoculation (day 0), when the product a_w had fallen to approximately 0.85, when the product a_w had fallen to approximately 0.60, and after 7 days of 22C vacuum-packaged storage. At each sampling time, three strips or sausages were sampled, with three sub-samples taken from each strip or sausage. The individual sub-sample sites per strip or sausage were consistent throughout the study and designated as end, between and middle. The "end" sample location was taken from the end of a strip or sausage, the "middle" sample location was taken from the midway point of the length of strip or sausage and the "between" sample location was taken from an area

TABLE 1.
WATER ACTIVITY (a_w), MPR, % FAT, pH AND %WPS OF BILTONG AND DROËWORS

Biltong					
Trial	a_w	MPR	% FAT	pH	% WPS
#1	0.75	0.50:1	NT	5.6	15.4
#2	0.67	0.41:1	NT	5.5	15.8
#3	0.62	0.31:1	9.1	5.5	21.5
Commercial	0.85	0.53:1	NT	5.6	13.5
Droëwors					
Trial	a_w	MPR	% FAT	pH	% WPS
#1	0.62	0.27:1	NT	5.5	19.1
#2	0.60	0.29:1	NT	5.4	19.6
#3	0.60	0.30:1	35.6	5.4	22.2
Commercial	0.74	0.42:1	NT	5.5	15.7

MPR, moisture: protein ratio; WPS, water-phase salt; NT, not tested.

between the end and the middle. Each sample was aseptically acquired by excision and was approximately 2.5 cm × 2.5 cm × 1.8 cm thick, and weighed about 4 g for biltong; droëwors samples were 2.5 cm × 1.3 cm × 1.3 cm thick, and weighed about 1.5 g. For analysis, three sub-samples of either end, between or middle were placed in a filter bag (15 × 23 cm, Nasco), along with 99 mL BPD, and pummeled in a stomacher for 2 min at medium speed (Stomacher 400 Circulator lab blender; Fisher). This initial dilution was arbitrarily denoted as 10^{-1}. From the initial dilution, 1.0 mL was distributed (0.3, 0.3 and 0.4 mL) for spread-plating among three plates of nutrient agar (NA; Difco), and from the original dilution and each subsequent dilution, 0.1 mL was spread on one NA plate per dilution. Plates were incubated at 35C for 1 h to allow for repair of injured cells, and then overlaid with xylose lysine desoxycholate (XLD) agar (Difco), MacConkey Sorbitol agar (SMAC; Difco), Baird-Parker agar base (B-P; Difco) with added egg yolk tellurite supplement (Difco), or Listeria Selective Agar base (LSA; Oxoid, Ogdensburg, NY) with added Listeria Selective Supplements (Oxford formulation; Oxoid). Plates were incubated at 35C (24 h for SMAC and XLD; 48 h for B-P and LSA) and then examined for typical colonies of *Salmonella* serovars (black on XLD), *E. coli* O157 : H7 (white-colorless on SMAC), *S. aureus* (black surrounded by clear to opaque clearing zone on B-P), and *L. monocytogenes* (grayish, small, surrounded by black precipitate on LSA). For simplicity, results were expressed as log CFU per sample for a given sub-sample location (end, middle

and between). For each sampling time, one colony of each organism was selected for confirmation testing, transferred to BHIA, and incubated at 35C for 18–24 h. Presumptive *Salmonella* serovar colonies were tested for oxidase activity and biochemical characteristics (API 20E kit, bioMérieux) and presumptive *E. coli* O157 : H7 colonies were tested for oxidase activity and O157 antigen latex agglutination (Oxoid, Ogdensburg, NY). Presumptive *S. aureus* colonies were tested for Gram stain, cellular morphology and Protein-A latex agglutination (Oxoid, Ogdensburg, NY). Presumptive *L. monocytogenes* colonies were tested for oxidase activity and biochemical characteristics (API Listeria kit, bioMérieux, Hazelwood, MO).

Data Analysis

Three samples of each product were analyzed for each inoculum at each sampling time. No difference in numbers of surviving pathogens was noted between the sample locations (end, between or middle), so the mean log CFU and standard deviation for the three locations combined were calculated for each sampling time. A value of 1 CFU less than the detection limit was assigned when no colonies were present for the least dilute plating. The two-sample *t*-test (Snedecor and Cochran 1980) was used to compare the level of a given pathogen at a given sampling time to that at the preceding sampling time within a single trial. A significance level of 5% ($P < 0.05$) was used.

RESULTS

Results for the proximate analyses of biltong and droëwors (Table 1) show that there was little difference in product pH between trials, and the experimental products had a pH similar to the commercial sample. However, the experimental products were drier (lower MPR and water activity) than the commercial products. Water activity fell steadily during the drying of biltong and droëwors. There was also some variation in MPR, water activity, and % water-phase salt between trials with trial 3 products having the highest % water-phase salt. The trial 3 droëwors had a much higher fat content than the trial 3 biltong.

As seen in Table 2, there was a general reduction in pathogen numbers throughout the drying and vacuum-storage of biltong. *Salmonella* serovar populations fell 2.0–3.3 log CFU by the time the a_w was approximately 0.85, with overall population decreases of 3.0–3.3 log CFU when the a_w was approximately 0.60, and 3.1–4.2 log CFU at the end of vacuum-storage. For *E. coli* O157 : H7, the corresponding population decreases were 2.0–

TABLE 2.
LETHALITY OF THE BILTONG MANUFACTURING PROCESS AGAINST *SALMONELLA* SEROVARS, *ESCHERICHIA COLI* O157:H7, *STAPHYLOCOCCUS AUREUS* AND *LISTERIA MONOCYTOGENES*

Sampling Time	*Salmonella* serovars		*E. coli* O157:H7		*S. aureus*		*L. monocytogenes*	
	Mean	Reduction	Mean	Reduction	Mean	Reduction	Mean	Reduction
Day 0								
Trial 1	6.4 (0.2)	–	6.6 (0)	–	6.8 (0.2)	–	6.8 (0.1)	–
Trial 2	6.6 (0.1)	–	6.9 (0.1)	–	6.9 (0.1)	–	6.6 (0.1)	–
Trial 3	6.9 (0.1)	–	6.9 (0)	–	7.1 (0)	–	6.6 (0.1)	–
a_w approx. 0.85								
Trial 1	4.4 (0.6)*	2.0	4.6 (0.1)*	2.0	5.9 (0.1)*	0.9	4.3 (0.1)*	2.5
Trial 2	3.3 (0.2)*	3.3	4.1 (0.2)*	2.8	5.8 (0.2)*	1.1	5.6 (0.1)*	1.0
Trial 3	4.4 (0.2)*	2.5	4.7 (0.2)*	2.2	6.6 (0.2)*	0.5	4.0 (0.3)*	2.6
a_w approx. 0.60								
Trial 1	3.4 (0.4)	3.0	3.8 (0.3)	2.8	5.1 (0.2)*	1.7	3.0 (0.1)*	3.8
Trial 2	3.4 (0.1)	3.2	4.1 (0.1)	2.8	5.7 (0.2)	1.2	4.4 (0.3)*	2.2
Trial 3	3.6 (0.2)*	3.3	4.1 (0.3)	2.8	Lab error	–	3.4 (0.4)	3.2
After 7-days vacuum-packaged storage at 22.2C								
Trial 1	2.2 (0.4)	4.2	2.2 (0.4)*	4.4	4.2 (0.1)*	2.6	2.8 (0.1)	4.0
Trial 2	3.1 (0.4)	3.5	3.5 (0.2)*	3.4	5.0 (0.3)	1.9	4.6 (0.1)	2.0
Trial 3	3.8 (0.2)*	3.1	4.1 (0.2)	2.8	5.4 (0.1)	1.7	2.6 (0.3)*	4.0

Each value is the mean log cfu/sample for three samples (end, between and middle) comprised of a sub-sample from each of three strips. The standard deviation is shown in parentheses. Reduction in log cfu/sample was calculated by subtracting the mean log cfu/sample at a given step from that determined at day-zero.

* Indicates mean log CFU per piece is significantly different ($P < 0.05$) from the mean in that trial for the preceding sampling time.

2.8 log CFU, 2.8 log CFU, and 2.8–4.4 log CFU. For both of these pathogens, populations decreased significantly ($P < 0.05$) relative to the preceding step during the first stage of drying (all trials) and occasionally thereafter.

The decreases in populations for *S. aureus* were generally smaller than for *Salmonella* serovars and *E. coli* O157 : H7. After drying, populations had fallen 1.2–1.7 log CFU and after vacuum-storage, the decreases were 1.7–2.6 log CFU. Step-to-step decreases in *S. aureus* population were significant for the first stage of drying (all trials) and for one trial each in the second stage of drying and in vacuum-storage.

Decreases in *L. monocytogenes* numbers were initially somewhat less than for *Salmonella* serovars and *E. coli* O157 : H7, but by the end of drying and vacuum-storage, *L. monocytogenes* die-off was very similar to that of these other two pathogens. Significant step-to-step decreases in population were observed after the first drying stage (all trials), the second drying stage (two trials) and after vacuum-storage (one trial).

TABLE 3.
LETHALITY OF THE DROËWORS MANUFACTURING PROCESS AGAINST *SALMONELLA* SEROVARS, *ESCHERICHIA COLI* O157 : H7, *STAPHYLOCOCCUS AUREUS*, AND *LISTERIA MONOCYTOGENES*.

Sampling Time	*Salmonella* serovars		*E. coli* O157 : H7		*S. aureus*		*L. monocytogenes*	
	Mean	Reduction	Mean	Reduction	Mean	Reduction	Mean	Reduction
Day 0								
Trial 1	6.2 (0.1)	–	6.5 (0)	–	6.5 (0)	–	6.3 (0)	–
Trial 2	6.5 (0.2)	–	6.8 (0.4)	–	6.0 (1.0)	–	6.4 (0.1)	–
Trial 3	6.7 (0.1)	–	6.9 (0.1)	–	7.3 (0.3)	–	6.6 (0.1)	–
a_w approx. 0.85								
Trial 1	5.1 (0.1)*	1.1	5.8 (0.6)*	0.7	5.8 (0.1)*	0.7	5.6 (0.1)*	0.7
Trial 2	4.7 (0.1)*	1.8	5.5 (0.2)*	1.3	5.3 (0.1)	0.7	4.8 (0.2)*	1.6
Trial 3	5.1 (0.1)*	1.6	5.8 (0.1)*	1.1	6.2 (0.1)*	1.1	4.6 (0.3)*	2.0
a_w approx. 0.60								
Trial 1	4.0 (0.1)*	2.2	4.1 (0.2)*	2.4	5.4 (0.1)*	1.1	4.8 (0.1)*	1.5
Trial 2	3.6 (0.1)*	2.9	4.4 (0.2)*	2.4	5.3 (0.1)	0.7	4.4 (0.1)	2.0
Trial 3	3.8 (0.3)*	2.9	3.9 (0.5)*	3.0	5.3 (0.3)*	2.0	3.7 (0.2)*	2.9
After 7-days vacuum-packaged storage at 22.2C								
Trial 1	3.9 (0.1)	2.3	4.1 (0.2)	2.4	4.6 (0.2)*	1.9	4.8 (0.4)	1.5
Trial 2	3.1 (0.3)	3.4	3.7 (0.3)*	3.1	4.4 (0.2)*	1.6	4.8 (1.2)	1.6
Trial 3	3.8 (0.4)	2.9	3.8 (0.6)	3.1	Lab error	–	3.9 (0.3)	2.7

Each value is the mean log cfu/sample for three samples (end, between, middle) comprised of a sub-sample from each of three sausages. The standard deviation is shown in parentheses. Reduction in log cfu/sample was calculated by subtracting the mean log cfu/sample at a given step from that determined at day-zero.

* Indicates mean log CFU per piece is significantly different ($P < 0.05$) from the mean in that trial for the preceding sampling time.

For droëwors, steady population decreases were obtained (Table 3), with significant step-to-step decreases frequently occurring during drying. Compared to vacuum-storage of biltong, vacuum-storage of droëwors was much less likely to cause a significant step-to-step decrease in pathogen numbers. Overall, the pathogen decreases associated with the manufacture of biltong were greater than those occurring during the manufacture of droëwors.

DISCUSSION

The results of our experimental trials can be applied to commercial products having final water activity, MPR, pH and % water-phase salt values at least as restrictive as in our trial products. It was clear from our results that drying of seasoned beef strips or sausage would result in significant reduction in numbers for all four pathogens tested. It also appears that higher fat content

in the droëwors product exerted a protective effect that more than compensated for the slightly higher % water-phase salt level in that product. Thus, processors should not apply our results to droëwors with a fat content higher than the 35.6% level in our trial 3 product. The lethality observed in the manufacturing of biltong and droëwors was less than that previously observed during the manufacture of basturma, a dry-cured product (Ingham *et al.* 2006). The basturma study used the same *Salmonella* serovars, *E. coli* O157 : H7, and *L. monocytogenes* strains as the present study and found that the basturma-making process resulted in decreases of 4.7–5.1, 4.9–5.4 and 4.0–4.9 log CFU, respectively. The corresponding decreases for biltong were 3.1–4.2, 2.8–4.4 and 2.0–4.0 log CFU, respectively, and for droëwors the corresponding decreases were 2.3–3.4, 2.4–3.1 and 1.5–2.7 log CFU. It is likely that the dry-curing and rinsing steps employed in making basturma increased the process lethality relative to that for biltong and droëwors.

The lethality achieved in making biltong and droëwors is not sufficient to meet USDA regulatory standards of either ≥6.5-log or ≥5-log reductions for beef products as stated in guidance for cooked products or fermented shelf-stable products, respectively (USDA Food Safety and Inspection Service 1999a, 2005a). However, these products could meet the alternative lethality standard of a ≥2-log reduction in *E. coli* O157 : H7 provided the starting material tested negative for this pathogen. It has not been determined whether the USDA will accept the application of the standards for fermented products to non-fermented biltong and droëwors. A prudent approach would be for processors of biltong and droëwors to add other anti-pathogen intervention treatments to their process. The USDA has indicated that the lethality of non-thermal steps can be counted toward meeting the overall process lethality (USDA Food Safety and Inspection Service 1999a) and steps such as spraying peracetic acid on the sub-primal from which the biltong and droëwors are made would likely allow a processor to meet the 5-log lethality standard. We found the peracetic acid spray treatment to dramatically reduce the levels of indigenous bacteria on the subprimals (data not shown). Other intervention strategies could include the application of acidified sodium chlorite (1,200 ppm) and acetic or lactic acid (2 or 4%). Researchers found spraying beef trim with these compounds reduced *E. coli* O157 : H7 and *Salmonella* Typhimurium levels by 1.5–2.0 log CFU (Harris *et al.* 2006).

In summary, the drying process used in making biltong and droëwors causes significant decreases in numbers of *Salmonella* serovars, *E. coli* O157 : H7, *S. aureus* and *L. monocytogenes*. In order to meet USDA requirements for process lethality, processors of these products should incorporate additional intervention treatments and/or raw material pathogen testing into their process.

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REFERENCES

ABERLE, E.D., FORREST, J.C., GERRARD, E.D. and MILLS, E.W. 2001. *Principles of Meat Science*, 4th Ed., pp. 151–153, 193–194, Kendall/ Hunt Publishing Co., Dubuque, IA.

HARRIS, K., MILLER, M.F., LONERGAN, G.H. and BRASHEARS, M.M. 2006. Validation of organic acids and acidified sodium chlorite to reduce *Escherichia coli* O157 and *Salmonella* Typhimurium in beef trim and ground beef in a simulated processing environment. J. Food Prot. *69*, 1802–1807.

INGHAM, S.C., SEARLS, G. and BUEGE, D.R. 2006. Inhibition of *Salmonella* serovars, *Escherichia coli* O157: H7 and *Listeria monocytogenes* during dry-curing and drying of meat: A case study with basturma. J. Food Safety *26*, 160–172.

INTERNATIONAL COMMISSION ON MICROBIOLOGICAL SPECIFICATIONS FOR FOODS, INTERNATIONAL UNION OF BIOLOGICAL SOCIETIES (ICMSF). 1996. *Microorganisms in Foods. 5. Characteristics of Microbial Pathogens*, p. 312, Blackie Academic & Professional, London.

JAY, J.M. 1992. *Modern Food Microbiology*, 4th Ed., p. 459, Chapman and Hall, New York.

SNEDECOR, G.W. and COCHRAN W.G. 1980. *Statistical Methods*, 7th Ed., pp. 91–93, The Iowa State University Press, Ames, IA.

UHLER, P. United States Department of Agriculture, Food Safety and Inspection Service. Personal communication, 2005.

UNITED STATES DEPARTMENT OF AGRICULTURE, FOOD SAFETY AND INSPECTION SERVICE. 1999a. FSIS Directive 7111.1, Performance standards for the production of certain meat and poultry products. http://www.fsis.usda.gov/OPPDE/rdad/FSISDirectives/7111-1.pdf (accessed September 28, 2006).

UNITED STATES DEPARTMENT OF AGRICULTURE, FOOD SAFETY AND INSPECTION SERVICE. 1999b. Compliance guidelines for meeting lethality performance standards for certain and poultry products. Appendix A. http://www.fsis.usda.gov/OA/fr/95033F-a.htm (accessed September 28, 2006).

UNITED STATES DEPARTMENT OF AGRICULTURE, FOOD SAFETY AND INSPECTION SERVICE. 2004. Compliance guidelines to control Listeria monocytogenes in post-lethality exposed ready-to-eat meat and poultry products. http://www.fsis.usda.gov/OPPDE/rdad/FRPubs/97-013F/CompGuidelines.pdf (accessed April 19, 2004).

UNITED STATES DEPARTMENT OF AGRICULTURE, FOOD SAFETY AND INSPECTION SERVICE. 2005a. Microbiology – shelf-stable dried meats. http://www.fsis.usda.gov/PDF/FSRE_SS_5MicrobiologyDried.pdf (accessed September 28, 2006).

UNITED STATES DEPARTMENT OF AGRICULTURE, FOOD SAFETY AND INSPECTION SERVICE. 2005b. Risk assessment of the impact of lethality standards on salmonellosis from ready-to-eat meat and poultry products; draft for public review and comment. http://www.fsis.usda.gov/PDF/Risk_Assessment_RTE_Salm_Leth_Main.pdf (accessed September 29, 2006).