

Research Note

Efficacy of Hypobromous Acid as a Hide-On Carcass Antimicrobial Intervention[†]

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ABSTRACT

Escherichia coli O157:H7 and *Salmonella* on cattle hides at slaughter are the main source of beef carcass contamination by these foodborne pathogens during processing. Hypobromous acid (HOBr) has been approved for various applications in meat processing, but the efficacy of HOBr as a hide antimicrobial has not been determined. In this study, the antimicrobial properties of HOBr were determined by spraying cattle hides at either of two concentrations, 220 or 500 ppm. Treatment of hides with 220 ppm of HOBr reduced the prevalence of *E. coli* O157:H7 on hides from 25.3 to 10.1% ($P < 0.05$) and reduced the prevalence of *Salmonella* from 28.3 to 7.1% ($P < 0.05$). Treatment of hides with 500 ppm of HOBr reduced ($P < 0.05$) the prevalence of *E. coli* O157:H7 on hides from 21.2 to 10.1% and the prevalence of *Salmonella* from 33.3 to 8.1%. The application of 220 ppm of HOBr reduced ($P < 0.05$) aerobic plate counts, total coliform counts, and *E. coli* counts on hides by 2.2 log CFU/100 cm². The use of 500 ppm of HOBr resulted in reductions ($P < 0.05$) of aerobic plate counts, total coliform counts, and *E. coli* counts by 3.3, 3.7, and 3.8 log CFU/100 cm², respectively, demonstrating that the use of higher concentrations of HOBr on hides resulted in additional antimicrobial activity. These results indicate that the adoption of a HOBr hide wash will reduce hide concentrations of spoilage bacteria and pathogen prevalence, resulting in a lower risk of carcass contamination.

The presence of *Escherichia coli* O157:H7 and *Salmonella* on cattle hides has been recognized as the principle source of carcass contamination at commercial beef processing facilities (2, 4, 5, 7, 8, 13, 20). Hide interventions proven to significantly reduce carcass contamination in processing facilities include chemical dehairing (20), cetylpyridinium chloride washing (8), and a 65°C sodium hydroxide wash followed by a water rinse (10). Ozonated water, electrolyzed oxidative water, and a minimal hide water wash followed by chlorine spray have also been demonstrated to significantly reduce hide contamination (3, 11). Hide-washing systems have been adopted by several beef processing plants, but space limitations, waste disposal issues, and costs have prevented wider adoption. Recently, the U.S. Food Safety and Inspection Service of the U.S. Department of Agriculture approved the use of hypobromous acid (HOBr) prepared from hydrogen bromide in aqueous solution without a

subsequent water rinse in the production of meat and poultry products without a labeling requirement (24).

Bromine-containing compounds have been widely used as disinfectants in water treatment systems. HOBr shares several disinfectant properties with hypochlorous acid, including high reactivity with most biological molecules (14). The use of HOBr in hide wash systems may have advantages over the use of hypochlorous acid since the bromamines formed by the reaction of HOBr with organic compounds are more reactive with biological molecules than the chloramines formed by hypochlorous acid reaction with organic compounds (14). Since the antimicrobial effects of HOBr when applied to cattle hides are unknown, the goals of this experiment were to determine the ability of HOBr to reduce the concentrations of indicator bacteria and the prevalence of *E. coli* O157:H7 and *Salmonella* on cattle hides at a processing plant.

MATERIALS AND METHODS

Experimental protocol. HOBr was prepared using 24% (wt/vol) hydrogen bromide in aqueous solution (HB2 HOBr precursor, EnviroTech Chemical Services Inc., Modesto, CA) according to the manufacturers' instructions. The concentration of HOBr was determined using a colorimeter (Hach Co., Loveland, CO).

Treatment with either 220 ppm ($n = 99$) or 500 ppm ($n = 99$) was evaluated. At a beef processing plant, hides were selected randomly from the processing line. The hides were collected

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immediately after removal from the carcasses and before hide processing steps occurred. To evaluate the treatment of hides with HOBr, whole pulled hides were draped over barrels to simulate hide-on carcasses. Prior to HOBr treatment, a pretreatment sample was obtained from a 500-cm² section of hide surface using a sterile sponge (Whirl-Pak, Nasco, Fort Atkinson, WI) prewetted with 20 ml of Dey-Engley neutralizing broth (BD, Franklin Lakes, NJ). A second pretreatment sample was obtained from a separate 500-cm² section of hide surface using a sterile sponge prewetted with 20 ml of buffered peptone water (BD) containing 0.002% (wt/vol) calcium carbonate (buffered peptone water plus CaCO₃). HOBr was applied to the hide using a sprayer at 45 psi at the source for 15 s, delivering 6 gal per min. The sprayer nozzle was maintained at a distance of 40 cm from the hide surface during spraying. Following a 2-min dwell period, two posttreatment samples were obtained, each from separate 500-cm² hide surface sections. One section was sampled with a sterile sponge prewetted with 20 ml of Dey-Engley neutralizing broth, while the other was sampled with a sterile sponge prewetted with 20 ml of buffered peptone water plus CaCO₃. Each sponge was placed into a sterile filter barrier bag (Whirl-Pak, Nasco) and massaged to ensure neutralization of samples prior to closing the bag. All samples were transported to the laboratory on ice and processed within 24 h. The sponge samples were homogenized by hand massage, and aliquots of the homogenate were transferred to microfuge tubes for the microbial analyses described below.

Aerobic plate count (APC), total coliform count (TCC), and *E. coli* count (ECC). Sample homogenates from sponges presoaked in buffered peptone water plus CaCO₃ were serially diluted, and 1-ml aliquots of the dilutions were plated onto PetriFilm aerobic count plates and PetriFilm *E. coli*/coliform count plates (3M Microbiology, St. Paul, MN). Plates were incubated and colonies counted according to the manufacturers' instructions.

***E. coli* O157:H7 and *Salmonella* enumeration.** *E. coli* O157:H7 and *Salmonella* bacteria were enumerated from hide samples using previously described methods (12). After being vortexed, homogenate samples from sponges presoaked in Dey-Engley neutralizing broth were held for 3 min to allow particulates to settle, and then 50- μ l amounts were spiral plated (Spiral Biotech, Norwood, MA) on Chromagar O157 plates (DRG International, Mountainside, NJ) supplemented with 5 mg of novobiocin per liter (Sigma, St. Louis, MO) and 2.5 mg of potassium tellurite per liter (nt-Chromagar; Sigma) and xylose lysine deoxycholate plates supplemented with 4.6 ml of Tergitol per liter, 15 mg of novobiocin per liter, and 5 mg of cefsulodin per liter (XLD_{inc}; Sigma). nt-Chromagar plates were incubated overnight at 42°C. XLD_{inc} plates were incubated overnight at 37°C and then at 25°C for 24 h. Suspected *E. coli* O157:H7 colonies were enumerated and screened using latex agglutination tests for the O157 antigen (DrySpot O157, Oxoid, Ltd., Basingstoke, UK), and up to six suspected colonies per sample were confirmed by multiplex PCR (15). Up to six suspected *Salmonella* colonies per XLD_{inc} plate were confirmed by PCR for the *Salmonella*-specific portion of the *invA* gene (21, 22). The lower limit of detection for enumeration of *E. coli* O157:H7 and *Salmonella* was 80 CFU/100 cm².

***E. coli* O157:H7 and *Salmonella* prevalence.** The prevalences of *E. coli* O157:H7 and *Salmonella* in hide samples were determined using previously described methods (6, 9, 19). Following the removal of aliquots for enumeration, the sponge samples were enriched in 80 ml of tryptic soy broth (BD) and incubated at 25°C for 2 h, 42°C for 6 h, and then 4°C overnight.

Salmonella cells were concentrated by immunomagnetic separation, and the immunomagnetic separation beads were then enriched by incubation in Rappaport-Vassiliadis-soy broth (Oxoid) at 42°C for 18 h. Cultures were then swabbed onto Hektoen enteric medium (BD) supplemented with 5 mg of novobiocin per liter and brilliant green agar supplemented with 80 mg of sulfadiazine per liter (BD). Suspected colonies were isolated and confirmed to be *Salmonella* by PCR (21, 22). *E. coli* O157:H7 was concentrated by immunomagnetic separation, and the immunomagnetic separation beads were plated onto nt-Chromagar. Suspected *E. coli* O157:H7 colonies were screened using latex agglutination tests for the O157 antigen (DrySpot O157, Oxoid) and confirmed by multiplex PCR (15).

Statistical analysis. APC, TCC, and ECC were log transformed, and the geometric means determined. Counts before and after HOBr treatment (220 ppm or 500 ppm) were compared using the two-tailed unpaired *t* test with Welch's correction for unequal variances performed with the Prism 5.0 program (GraphPad Software, La Jolla, CA); comparisons with *P* values of <0.05 were considered significant. Differences in the proportions of prevalence-positive samples and enumerable samples were examined by a two-tailed Fisher exact chi-square test performed with the WINPEPI Compare2 program (1). Comparisons with *P* values of <0.05 were considered significant.

RESULTS AND DISCUSSION

Both concentrations of HOBr tested resulted in significant reductions (*P* < 0.05) of indicator organism concentrations, *E. coli* O157:H7 prevalence, and *Salmonella* prevalence. The geometric means of the indicator organism counts on the 99 samples treated with 220 ppm of HOBr were 8.4 log APC/100 cm², 6.5 log TCC/100 cm², and 6.4 log ECC/100 cm² prior to the HOBr treatment (Table 1). The 220-ppm HOBr treatment reduced (*P* < 0.05) APC, TCC, and ECC counts by 2.2 log. Increasing the concentration of HOBr to 500 ppm resulted in greater reductions (*P* < 0.05) of indicator organism counts. Following the 500-ppm HOBr treatment, APC was reduced 3.3 log, TCC was reduced 3.7 log, and ECC was reduced 3.8 log (Table 1). The use of 500 ppm of HOBr resulted in a log reduction of TCC on hides similar to that observed for 4% chlorofoam and a greater log reduction of TCC than was observed when 4% phosphoric acid, 1.6% sodium hydroxide, or 4% trisodium phosphate was used (10). Treatment of hides with 500 ppm of HOBr resulted in a log reduction of APC that was similar to that observed with electrolyzed water treatment of hides and was greater than that observed with treatment of hides with 60°C water or ozonated water (11).

The prevalence of *E. coli* O157:H7 on hides was reduced at both concentrations of HOBr tested (Table 2). Treatment with 220 ppm of HOBr reduced (*P* < 0.05) the prevalence of *E. coli* O157:H7 on hides from 25.3 to 10.1%. Washing hides with 500 ppm of HOBr reduced (*P* < 0.05) the prevalence of *E. coli* O157:H7 from 21.2 to 10.1%. These reductions in the prevalence of *E. coli* O157:H7 on cattle hides were similar to those observed when cattle hides were treated with cetylpyridinium chloride, 1.6% sodium hydroxide, ozonated water, and electrolyzed water (8, 10, 11). The reduction of *E. coli* O157:H7 concentration on

TABLE 1. Levels of indicator bacteria pre- and posttreatment with HOBr

Treatment, sample	No. of samples	Geometric mean log count/100 cm ² or log reduction as indicated (95% CI) ^a		
		Aerobic plate count	Total coliform count	<i>E. coli</i> count
220 ppm of HOBr				
Pretreatment	99	8.4 (8.3–8.5) A	6.5 (6.3–6.7) A	6.4 (6.2–6.5) A
Posttreatment	99	6.2 (5.9–6.5) B	4.3 (4.0–4.6) B	4.1 (3.8–4.4) B
500 ppm of HOBr				
Pretreatment	99	8.6 (8.5–8.7) C	6.5 (6.3–6.6) C	6.3 (6.1–6.5) C
Posttreatment	99	5.3 (5.1–5.5) D	2.7 (2.5–3.0) D	2.5 (2.2–2.8) D
Log reduction				
220 ppm of HOBr	99	2.2 (2.0–2.4) E	2.2 (2.0–2.4) E	2.2 (2.0–2.5) E
500 ppm of HOBr	99	3.3 (3.3–3.5) F	3.7 (3.5–4.0) F	3.8 (3.6–4.1) F

^a Within the same column, means from each treatment that do not have a common letter are significantly different ($P < 0.05$).

hides has been demonstrated to be an effective means of reducing the contamination of carcasses (3, 10, 20). *E. coli* O157:H7 was not enumerable from any of the 396 samples obtained during this study, so we could not determine whether HOBr treatment was effective in reducing the concentration of *E. coli* O157:H7 on hides. However, our laboratory recently demonstrated that spray treatment of inoculated beef carcass surfaces and beef hearts with the antimicrobial 1,3-dibromo-5,5-dimethylhydantoin, which hydrolyzes to its active HOBr form in aqueous solution (23), was effective in reducing the levels of *E. coli* O157:H7 by 1.6 to 2.1 log CFU/100 cm² (16). Since we were able to demonstrate that HOBr reduced *E. coli* concentrations (ECC/100 cm²) by 2.2 to 3.8 log (Table 1), it is reasonable to assume that enumerable *E. coli* O157:H7 concentrations, when present on hides, would be reduced by a similar level (4, 18).

TABLE 2. Prevalence and enumeration of *E. coli* O157:H7 and *Salmonella* pre- and post-HOBr treatment

Organism, treatment, sample	No. of samples	%	No. of samples enumerated		
			80–99 CFU/100 cm ²	100–999 CFU/100 cm ²	>999 CFU/100 cm ²
<i>E. coli</i> O157:H7					
220 ppm of HOBr					
Pretreatment	99	25.3 A	0	0	0
Posttreatment	99	10.1 B	0	0	0
500 ppm of HOBr					
Pretreatment	99	21.2 C	0	0	0
Posttreatment	99	10.1 D	0	0	0
<i>Salmonella</i>					
220 ppm of HOBr					
Pretreatment	99	28.3 E	11	8	0
Posttreatment	99	7.1 F	4	0	0
500 ppm of HOBr					
Pretreatment	99	33.3 G	7	3	0
Posttreatment	99	8.1 H	1	6	0

^a Results from each treatment that do not have a common letter are significantly different ($P < 0.05$).

Treatment of hides with 220 ppm of HOBr reduced ($P < 0.05$) the *Salmonella* prevalence on hides from 28.3 to 7.1% (Table 2). Prior to treatment with 220 ppm of HOBr, 19.2% of hides had enumerable concentrations of *Salmonella* that ranged from 80 to 400 CFU/100 cm². Following the 220-ppm HOBr treatment, only 4.0% of hides had enumerable concentrations of *Salmonella* and the concentration for all enumerated hides was 80 CFU/100 cm², the lower detection limit of enumeration (Table 2). The use of 500 ppm of HOBr reduced ($P < 0.05$) the prevalence of *Salmonella* on hides from 33.3 to 8.1%. Prior to treatment with 500 ppm of HOBr, *Salmonella* bacteria were enumerated from 10.1% of hides with concentrations ranging from 80 to 320 CFU/100 cm². Following the 500-ppm HOBr treatment, *Salmonella* bacteria were enumerated from 7.1% of hides with concentrations ranging from 80 to 880 CFU/100 cm² (Table 2). The presence of higher *Salmonella* concentrations on some of the 500-ppm-treated hides is most likely a product of unequal distribution of pathogens on hides, which our laboratory has demonstrated occurs (17).

In summary, spraying HOBr on cattle hides significantly reduced the prevalences of *E. coli* O157:H7 and *Salmonella* and indicator organism concentrations (APC, TCC, and ECC) (Tables 1 and 2). The results of this study suggest that HOBr treatment of cattle hides is as effective or more effective as a hide intervention than treatment with hot water, chlorofoam, phosphoric acid, sodium hydroxide, trisodium phosphate, ozonated water, or electrolyzed water. Thus, the adoption of a HOBr hide wash by cattle processors should be effective in reducing carcass contamination. Additionally, we suggest that processors currently using HOBr in carcass washes could improve food safety with a minimal increase in cost by reusing the HOBr carcass wash to treat hides.

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REFERENCES

1. Abramson, J. H. 2011. WINPEPI updated: computer programs for epidemiologists, and their teaching potential. *Epidemiol. Perspect. Innov.* 8:1.

2. Arthur, T. M., J. M. Bosilevac, D. M. Brichta-Harhay, M. N. Guerini, N. Kalchayanand, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2007. Transportation and lairage environment effects on prevalence, numbers, and diversity of *Escherichia coli* O157:H7 on hides and carcasses of beef cattle at processing. *J. Food Prot.* 70:280–286.
3. Arthur, T. M., J. M. Bosilevac, D. M. Brichta-Harhay, N. Kalchayanand, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2007. Effects of a minimal hide wash cabinet on the levels and prevalence of *Escherichia coli* O157:H7 and *Salmonella* on the hides of beef cattle at slaughter. *J. Food Prot.* 70:1076–1079.
4. Arthur, T. M., J. M. Bosilevac, X. Nou, S. D. Shackelford, T. L. Wheeler, M. P. Kent, D. Jaroni, B. Pauling, D. M. Allen, and M. Koohmaraie. 2004. *Escherichia coli* O157 prevalence and enumeration of aerobic bacteria, *Enterobacteriaceae*, and *Escherichia coli* O157 at various steps in commercial beef processing plants. *J. Food Prot.* 67:658–665.
5. Barkocy-Gallagher, G. A., T. M. Arthur, M. Rivera-Betancourt, X. Nou, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2003. Seasonal prevalence of Shiga toxin-producing *Escherichia coli*, including O157:H7 and non-O157 serotypes, and *Salmonella* in commercial beef processing plants. *J. Food Prot.* 66:1978–1986.
6. Barkocy-Gallagher, G. A., K. K. Edwards, X. Nou, J. M. Bosilevac, T. M. Arthur, S. D. Shackelford, and M. Koohmaraie. 2005. Methods for recovering *Escherichia coli* O157:H7 from cattle fecal, hide, and carcass samples: sensitivity and improvements. *J. Food Prot.* 68:2264–2268.
7. Bosilevac, J. M., T. M. Arthur, J. L. Bono, D. M. Brichta-Harhay, N. Kalchayanand, D. A. King, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2009. Prevalence and enumeration of *Escherichia coli* O157:H7 and *Salmonella* in U.S. abattoirs that process fewer than 1000 head of cattle per day. *J. Food Prot.* 72:1272–1278.
8. Bosilevac, J. M., T. M. Arthur, T. L. Wheeler, S. D. Shackelford, M. Rossman, J. O. Reagan, and M. Koohmaraie. 2004. Prevalence of *Escherichia coli* O157 and levels of aerobic bacteria and *Enterobacteriaceae* are reduced when hides are washed and treated with cetylpyridinium chloride at a commercial beef processing plant. *J. Food Prot.* 67:646–650.
9. Bosilevac, J. M., M. N. Guerini, N. Kalchayanand, and M. Koohmaraie. 2009. Prevalence and characterization of salmonellae in commercial ground beef in the United States. *Appl. Environ. Microbiol.* 75:1892–1900.
10. Bosilevac, J. M., X. Nou, M. S. Osborn, D. M. Allen, and M. Koohmaraie. 2005. Development and evaluation of an on-line hide decontamination procedure for use in a commercial beef processing plant. *J. Food Prot.* 68:265–272.
11. Bosilevac, J. M., S. D. Shackelford, D. M. Brichta, and M. Koohmaraie. 2005. Efficacy of ozonated and electrolyzed oxidative waters to decontaminate hides of cattle before slaughter. *J. Food Prot.* 68:1393–1398.
12. Brichta-Harhay, D. M., T. M. Arthur, J. M. Bosilevac, M. N. Guerini, N. Kalchayanand, and M. Koohmaraie. 2007. Enumeration of *Salmonella* and *Escherichia coli* O157:H7 in ground beef, cattle carcass, hide and faecal samples using direct plating methods. *J. Appl. Microbiol.* 103:1657–1668.
13. Brichta-Harhay, D. M., M. N. Guerini, T. M. Arthur, J. M. Bosilevac, N. Kalchayanand, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2008. *Salmonella* and *Escherichia coli* O157:H7 contamination on hides and carcasses of cull cattle presented for slaughter in the United States: an evaluation of prevalence and bacterial loads by immunomagnetic separation and direct plating methods. *Appl. Environ. Microbiol.* 74:6289–6297.
14. Carr, A. C., J. J. van den Berg, and C. C. Winterbourn. 1998. Differential reactivities of hypochlorous and hypobromous acids with purified *Escherichia coli* phospholipid: formation of haloamines and haloaldehydes. *Biochim. Biophys. Acta* 1392:254–264.
15. Hu, Y., Q. Zhang, and J. C. Meitzler. 1999. Rapid and sensitive detection of *Escherichia coli* O157:H7 in bovine faeces by a multiplex PCR. *J. Appl. Microbiol.* 87:867–876.
16. Kalchayanand, N., T. M. Arthur, J. M. Bosilevac, D. M. Brichta-Harhay, M. N. Guerini, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2009. Effectiveness of 1,3-dibromo-5,5 dimethylhydantoin on reduction of *Escherichia coli* O157:H7- and *Salmonella*-inoculated fresh meat. *J. Food Prot.* 72:151–156.
17. Kalchayanand, N., D. M. Brichta-Harhay, T. M. Arthur, J. M. Bosilevac, M. N. Guerini, T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2009. Prevalence rates of *Escherichia coli* O157:H7 and *Salmonella* at different sampling sites on cattle hides at a feedlot and processing plant. *J. Food Prot.* 72:1267–1271.
18. Marshall, K. M., S. E. Niebuhr, G. R. Acuff, L. M. Lucia, and J. S. Dickson. 2005. Identification of *Escherichia coli* O157:H7 meat processing indicators for fresh meat through comparison of the effects of selected antimicrobial interventions. *J. Food Prot.* 68:2580–2586.
19. Nou, X., T. M. Arthur, J. M. Bosilevac, D. M. Brichta-Harhay, M. N. Guerini, N. Kalchayanand, and M. Koohmaraie. 2006. Improvement of immunomagnetic separation for *Escherichia coli* O157:H7 detection by the PickPen magnetic particle separation device. *J. Food Prot.* 69:2870–2874.
20. Nou, X., M. Rivera-Betancourt, J. M. Bosilevac, T. L. Wheeler, S. D. Shackelford, B. L. Gwartney, J. O. Reagan, and M. Koohmaraie. 2003. Effect of chemical dehairing on the prevalence of *Escherichia coli* O157:H7 and the levels of aerobic bacteria and enterobacteriaceae on carcasses in a commercial beef processing plant. *J. Food Prot.* 66:2005–2009.
21. Nucera, D. M., C. W. Maddox, P. Hoiem-Dalen, and R. M. Weigel. 2006. Comparison of API 20E and *invA* PCR for identification of *Salmonella enterica* isolates from swine production units. *J. Clin. Microbiol.* 44:3388–3390.
22. Rahn, K., S. A. De Grandis, R. C. Clarke, S. A. McEwen, J. E. Galan, C. Ginocchio, R. Curtiss III, and C. L. Gyles. 1992. Amplification of an *invA* gene sequence of *Salmonella typhimurium* by polymerase chain reaction as a specific method of detection of *Salmonella*. *Mol. Cell. Probes* 6:271–279.
23. Song, S., P. Lui, and Q. J. Song. 2007. Quantification of dibromodimethylhydantoin disinfectants in water by chemiluminescent method. *Anal. Sci.* 23:327–330.
24. U.S. Department of Agriculture, Food Safety and Inspection Service. 2011. Safe and suitable ingredients used in the production of meat, poultry, and egg products, Directive 7120.1 Rev. 7. U.S. Department of Agriculture, Food Safety and Inspection Service, Washington, DC. Available at: <http://www.fsis.usda.gov/oppde/rdad/fsisdirectives/7120.1.pdf>. Accessed March 2012.