Postharvest Pathogen Interventions for Meat and Poultry

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Introduction

Although progress has been made in regard to pathogen reduction technologies, the incidence and retardation of pathogens in the meat supply remains a high priority. As examples, on October 7, 2002, the Food Safety and Inspection Service (FSIS) issued a notice in the Federal Register mandating HACCP reassessments for *E. coli* O157:H7 and indicated that testing exemptions would furthermore be revoked. As promised, and due to the "*E. coli* summer season," on April 18, 2003, the FSIS issued Notice 11-03 indicating that the FSIS will begin sampling raw ground products for *E. coli* O157:H7 at **all** grinding facilities, regardless if an establishment was previously exempt from routine sampling, in effect removing all exemptions. To this end, in-plant inspectors will receive sampling request forms and draw samples regardless of the plants own testing program.

Therefore, the use of decontamination methods for meat remains important to ensure the safety of muscle foods. Long recognizing the importance of these technologies, substantial research has focused on development of antimicrobial interventions. Antimicrobial interventions researched for meat have included various organic acids and their salts, chlorinated compounds, quaternary ammonia-like compounds, various buffers, rinses, ozone/oxidizers, hot water, steam pasteurization and vacuum, chelators and baceriocins to name a few. Reductions from these technologies have ranged from less than one $\log_{10}$ (log) reduction to several log reductions depending on efficacy of the treatment and initial microbial loads before treatment. To this end, a number of these technologies are currently being used in the meat industry to improve meat safety. However, the vast body of these technologies have been researched, developed and implemented for carcass decontamination applications. While these technologies either are or have the potential for reducing pathogens in the meat supply, a substantial opportunity for pathogen reduction exists postharvest. While carcass interventions are an important part of a concerted intervention strategy, they do not render the carcass sterile. Therefore, subsequent fabrication where cuts are exposed to conveyor belts, knives, human hands etc. through the normal course of fabrication expose meat cuts to cross and recontamination vectors which therefore may not lead to microbial reductions in final products. Therefore, substantial opportunity exists to not only decontaminate carcasses but also decontaminate cuts and meat pieces postharvest, closer to the packaging phase to provide microbial reductions that can be achieved in the final package selected by the consumer. With either the postharvest or carcass then postharvest intervention strategies in a multiple intervention approach, it is only recently that research has addressed these types of applications. However, a wealth of knowledge can be gleaned from past carcass intervention research, particularly where muscles were excised then treated with various antimicrobial interventions. While these studies focused on applying the reductions achieved on excised tissues back to the carcass, they certainly could have applications forward to retail cuts or trimmings destined for ground beef and lead to reductions in pathogens in the meat supply directly purchased by the consumer.

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Proceedings of the 56th American Meat Science Association Reciprocal Meat Conference *(pp. 39-47)*
June 15-18, 2003, Columbia, Missouri
www.meatscience.org

Postharvest interventions for beef cuts or tissues

While substantial research has been conducted on microbial interventions for carcasses, less work has been conducted and published on postharvest interventions. However, a number of carcass intervention studies have used excised tissue to test antimicrobial effectiveness and although the focus was for carcass decontamination, these carcass decontamination technologies might have application for retail cuts or ground beef. For studies where tissue was excised and treated with antimicrobial interventions, one can get a sense of how these technologies might perform on primals, subprimals, retail cuts or trimmings, if that was their intended application. Therefore, for brevity, this paper reviews only selected tissue studies and not carcass applications for direct reductions in microorganisms. Likewise, for brevity, irradiation, although a postharvest pathogen reduction technology, is also not discussed.

Table 1 illustrates selected studies for postharvest pathogen reductions on beef cuts or tissues, beef trimmings destined for ground beef and direct ground beef interventions. This table also shows possible ranges for microbial reductions with the use of these individual interventions. Numerous technologies have been researched for the reduction of microorganisms on beef tissues. Organic acids such as lactic acid, acetic acid, formic acid, citric acid and gluconic acid have shown abilities to reduce *E. coli*, coliforms, aerobic bacteria and *Salmonella spp.* However, like other intervention technologies, organic acids have shown variability in their ability to reduce microbial loads. These variations can sometimes be explained by concentrations, duration of application, application techniques, microbial load or microbial resilience, but substantial unexplained variation still exist. Lactic acid has been observed to reduce *E. coli* on beef tissue by 0.2 log (Kotula and Thelappurate, 1994) up to greater than 3 log reductions (Dorsa *et al.*, 1998a). In additional studies some enhancement in microbial reduction, including *E. coli* reduction might be accomplished by heating organic acids before application to beef tissue (Anderson and Marshall, 1990a,b; Anderson *et al.*, 1979). With coliforms, a common fecal bacterial contaminant, lactic acid has shown reductions from 0.6 log to greater than 1 log reduction (Anderson and Marshall, 1990b). Aerobic bacteria are also susceptible to lactic acid treatments and can be reduce from 0.8 (Anderson and Marshall, 1990b) to greater than 2 log reductions (Dorsa *et al.*, 1997). *Salmonella* has also shown a similar susceptibility response to lactic acid as *E. coli* with reductions from 0.7 log to greater than 3 logs possible (Dorsa *et al.*, 1998a). Acetic acid has produced similar microbial reductions as lactic acid. Using acetic acid on beef shortloins, Bala *et al.* (1977) was able to reduce *E. coli* in excess of 3 logs. Furthermore, Dickson (1991) was able to reduce *Salmonella typhimurium* on beef trimmings by up to 3 logs using acetic acid.

Other organic acids tested on beef tissue have included formic (Bell *et al.*, 1986), citric (Brackett *et al.*, 1994) and gluconic (Garcia-Zepeda et al, 1994) acids. In general, these have not shown the same effectiveness for maximum microbial reductions on beef tissues or cuts as lactic and acetic acids, although they have not been as widely researched. Microbial reductions reported have generally been below 1 log for any given microorganism using these organic acids.

Another approach for using organic acids has been multiple organic acid mixtures (Anderson and Marshall, 1990a; Goddard *et al.*, 1996). However, in limited studies, mixtures of organic acids seem to yield similar microbial reductions as single organic acid applications (Table 1).

Sodium hypochlorite and hypochlorous acids have also been evaluated on beef tissue for aerobic bacteria reduction. Aerobic bacteria reductions have been reported between 0.2 log and 1.0 log (Anderson *et al.*, 1979; Johnson *et al.*, 1979).

One of the most effective antimicrobial inhibitors in beef tissue reported has been cetylpyridinium chloride (CPC), a compound commonly found in oral hygiene products. Cutter *et al.* (2000) reported up to 6 log reductions to virtually undetectable levels for *E. coli* and *Salmonella* on beef lean when beef shortplates and *cutaneous trunci* muscles were treated with 1% CPC. Another compound, which has shown abilities to reduce microorganisms on beef tissue, is trisodium phosphate (TSP). Dorsa *et al.* (1998a) reported trisodium phosphate reduced *E. coli* and *Salmonella typhimurium* by greater than 4 logs on beef neck tissue.

Other interventions such as cold water and hot water rinses have also been evaluated for reducing microorganisms on beef tissues. In general and as expected, hot water has often produced higher microbial reductions than cold water. Reductions up to and in excess of 2 logs have been reported for aerobic plate counts (APC), *E. coli*, and *Salmonella spp.* using hot water rinses (Anderson *et al.*, 1979; Dorsa, 1998a). In addition to water, steam has also been evaluated on beef tissues for microbial reduction. However, although there has been substantial research conducted with steam on beef carcasses, surprisingly little data has been reported for the use of steam in postharvest applications. In one study, Anderson *et al.* (1979) reported only 0.1 log reduction in APC using steam, however, based on carcass research, it would appear likely that substantially greater microbial reductions could be achieved using steam applications postharvest. In other work, instead of chemical interventions, Pohlman *et al.* (1997) had some effect on aerobic bacteria reduction on beef muscle using low intensity ultrasound.

An area that may hold promise regarding maximum microbial reductions might be the use of multiple antimicrobial interventions at multiple stages of production. The use of "hurdle" technology may show particularly advantageous benefits should the most effective antimicrobials be utilized in a multiple intervention approach. Utilizing multiple interventions, Kang *et al.*, (2001a and 2001b) and Kondaih *et al.* (1985) demonstrated that it is possible to reduce pathogens and aerobic bacteria in excess of 2 logs on beef tissue.

Postharvest interventions for beef trimmings destined for ground beef

While the safety of beef cuts remains a concern, perhaps more importantly is the safety of ground beef. Because ground beef is often produced from beef trimmings from numerous animals and because of grinding and mixing operations, which more equally distribute any microorganisms present as well incorporating air, the potential for ground beef to harbor pathogens remains a concern. Therefore, decontamination of trimmings before grinding or of ground beef post grinding might be advantageous to reduce microbial loads in ground beef. These postharvest applications have only been recently explored.

Using cold or hot water on beef trimmings before grinding has been shown to reduce *E. coli* and *Salmonella typhi-*

murium by up to 2 logs in ground beef (Dorsa *et al.*, 1998a; Ellebracht *et al.*, 1999 and Stivarius *et al.*, 2002)(Table 1). Additionally, lactic and acetic acid treatments have also been used to decontaminate beef trimmings before grinding (Stivarius *et al.*, 2002a; Conner *et al.*, 1997 and Dorsa *et al.*, 1998a) and have achieved *E. coli* and *Salmonella typhimurium* reductions by up to 3 logs in ground beef. Using gluconic acid and trisodium citrate, Stivarius *et al.* (2002b) reduced *E. coli*, *Salmonella typhimurium*, coliforms and aerobic bacteria in ground beef by less than 1 log. However, Stivarius *et al.* (2002c) reported slightly greater reductions for these same microorganisms in ground beef using chlorine dioxide or ozonated water wash of beef trimmings before grinding.

Although ground beef is one of the most difficult meat products to reduce microorganisms in, trisodium phosphate has been demonstrated to reduce *E. coli*, *Salmonella typhimurium*, coliforms and aerobic bacteria in ground beef when applied to beef trimmings (Pohlman *et al.*, 2002b; Dorsa *et al.*, 1998a; Dorsa *et al.*, 1998b). Reductions in *E. coli* in ground beef in excess of 2 logs and *Salmonella typhimurium* in excess of 3 logs has been observed from treated trimmings. Another intervention, cetylpyridinium chloride, used on beef trimmings before grinding, has been reported to reduce *E. coli*, *Salmonella typhimurium*, coliforms and aerobic bacteria in ground beef by <1 log (Pohlman *et al.*, 2002b). These findings illustrate the difficulty for reducing microorganisms in ground beef when compared to reductions in microorganisms on beef tissue when comparing up to a 6 log reduction when cetylpyridinium chloride was used on beef tissue surfaces (Cutter *et al.*, 2000).

Interestingly, using multiple "hurdle" interventions on beef trimmings prior to grinding has been shown to be more effective for reducing microorganisms in ground beef than its single intervention counterparts. In a series of studies (Pohlman *et al.*, 2002b; Pohlman *et al.*, 2002c) showed reductions in *E. coli*, *Salmonella typhimurium*, coliforms and aerobic bacteria in ground beef up to and in excess of 2 logs when multiple interventions were applied to beef trimmings before grinding. Therefore, the use of multiple or "hurdle" technology might show promise for the safety improvement of ground beef.

In addition to treatment of beef trimmings before grinding to improve ground beef safety, a number of direct additives or technologies have been applied to ground beef. Ajjarapu and Shelef (1999) found that the addition of sodium lactate or diacetate to ground beef delayed growth of *E. coli* in storage. Likewise, Meca *et al.* (1997) reported that direct addition of sodium acetate reduced aerobic bacteria in ground beef from 0.1 to 0.6 logs and that buffered citrate/sodium citrate reduced APC by up to 0.2 logs. Egbert *et al.* (1992) found that potassium lactate reduced coliforms by up to 1 log and aerobic bacteria by up to 0.8 log in ground beef. An additional technology for reducing pathogens in ground beef is that of hydrostatic pressure. Using hydrostatic pressure, Carballo *et al.* (1997) was able to reduce *E. coli* in ground beef by up to approximately 2 logs.

Postharvest interventions for poultry, pork & lamb

As with beef, much of the published research regarding microbial interventions for poultry, pork and lamb has involved carcass decontamination. While the industry has done substantial research on postharvest interventions, less peer-reviewed research is available. This is particularly true for poultry with much of the work involving chill decontamination of carcasses. Additionally, due to the small carcass size and rapid fabrication rates, it is also likely that this has lead to a history of more carcass decontamination work and less postharvest decontamination research. However, it is apparent that the poultry industry also recognizes the benefits that postharvest decontamination may provide. Since many of the same interventions as beef have been attempted on poultry, Table 2 shows examples of selected postharvest interventions for poultry, pork and lamb as well as a some additional interventions researched on poultry carcasses not previously discussed.

Using acidified sodium chlorite, Kemp *et al.* (2001) was able to reduce *E. coli*, *Salmonella spp.* and *Campylobacter spp.* on chicken carcasses by 2.3, 2.0 and 2.6 logs, respectively. Additionally, Kemp *et al.* (2000) found that acidifying with citric acid gave substantially better microbial reductions than acidifying with phosphoric acid. Trisodium phosphate, lactic acid, cetylypyridinium chloride and sodium bisulfate have also been researched for reducing microorganisms on poultry (Yang and Slavik, 1988; Lillard, 1994; Wang *et al.*, 1997; Breen *et al.*, 1997 and Xiong *et al.*, 1998). Reductions in aerobic bacteria up to 4.9, 1.8, 2.3 and 1.7 logs have been reported for trisodium phosphate, lactic acid, cetylypyridinium chloride and sodium bisulfate, respectively. For postharvest interventions, Hwang and Beuchat were able to reduce *Salmonella spp.*, *Campylobacter spp.*, *L. monocytogenes*, *S. aureus* and *E. coli* by 2.5, 1.0, 0.5, 1.5, and 1.3 logs, respectively on chicken wings using lactic acid and sodium benzoate.

In other poultry postharvest research, hydrostatic pressure has been used to reduce pathogens and microorganisms in ground chicken and various meat models. Hydrostatic pressure up to 700MPa has been reported to reduce Listeria *spp.*, *Salmonella spp.*, *E. coli* and *S. aureus* by up to 7.5, 2.0, 6.0 and 6.0 logs, respectively in ground poultry (Patterson *et al.*, 1995; Patterson *et al.*, 1998; Yuste *et al.*, 1999).

Postharvest decontamination of turkeys has also seen research activity. Kalinowski and Tomkin (1999) were able to reduce Clostridium *spp.* on turkey breast cores by up to 0.8 logs using sodium diacetate or a combination of sodium lactate and sodium diacetate. Whereas Schlyter *et al.* (1993) was able to reduce *L. monocytogenes* in ready to eat turkey breasts by up to almost 5.0 logs using combinations of sodium lactate, diacetate and nitrate. However, Schlyter *et al.* (1993) found the greatest reductions in *L. monocytogenes* occurred when pediocin was combined with sodium diacetate.

Table 1. Selected postharvest interventions for beef tissue, cuts or in ground beef.

Antimicrobial	Microorganism	Inhibition (logs)	Reference
Beef cuts/tissues			
Lactic acid Ambient or heated	*E. coli* Coliforms APC *S. typhimurium*	0.2-3.1 0.6-1.1 0.8-2.5 0.7-3.0	Anderson & Marshall, 1990b; Brackett *et al.*, 1994; Kotula & Thelappurate, 1994; Dorsa *et al.*, 1998a; Dorsa *et al.*, 1997
Acetic acid Ambient or heated	*E. coli* Coliforms APC *S. typhimurium*	0.3-3.2 0.7-1.75 1.1-3.4 0.5-3.0	Anderson & Marshall, 1989; Anderson *et al.*, 1979; Bala *et al.*, 1977; Bell *et al.*, 1986; Brackett *et al.*, 1994; Dickson, 1992; Dickson, 1991; Dickson & Siragusa, 1994; Kotula & Thelappurate, 1994; Dorsa *et al.*, 1998b; Dorsa *et al.*, 1997
Formic acid	*E. coli* Coliforms *S. typhimurium*	<1.0 <1.0 <1.0	Bell *et al.*, 1986
Citric acid	*E. coli*	<0.3	Brackett *et al.*, 1994
Gluconic acid	Psychrotrophs Lactic acid bacteria	0.2-0.5 0.7	Garcia-Zepeda *et al.*, 1994
Mixed organic acids Ambient or heated	*E. coli* Coliforms APC *S. typhimurium*	0.4-0.9 0.7-1.6 0.6-1.7 0.8-1.7	Anderson & Marshall, 1990a; Goddard *et al.*, 1996
Sodium hypochlorite/ Hypochlorous acid	APC	0.2-1.0	Anderson *et al.*, 1979; Johnson *et al.*, 1979
Cetylpyridinium chloride	*E. coli* *S. typhimurium*	5.0-6.0 5.0-6.0	Cutter *et al.*, 2000
Trisodium phosphate	*E. coli* Coliforms APC *S. typhimurium*	0-4.3 0.1-0.3 0.1-2.9 0.5-4.1	Dorsa *et al.*, 1998a; Dorsa *et al.*, 1998b; Fratamico *et al.*, 1996; Dickson *et al.*, 1994; Delmore *et al.*, 2000; Kim & Slavik, 1994; Dorsa *et al.*, 1997
Cold water	APC *E. coli* Coliforms *S. typhimurium*	0.1-1.2 0.3-1.0 1.1 0.3-0.9	Anderson *et al.*, 1979; Kang *et al.*, 2001b; Dorsa *et al.*, 1998a
Hot water	APC *E. coli* *S. typhimurium*	1.5-2.2 1.3-2.7 2.5-2.2	Anderson *et al.*, 1979; Dorsa *et al.*, 1998a
Steam	APC	0.1	Anderson *et al.*, 1979
Low intensity Ultrasound	APC	0.2	Pohlman *et al.*, 1997
Multiple interventions	*E. coli* Coliforms APC	1.3-2.2 1.2-2.2 1.0-2.5	Kang *et al.*, 2001a; Kang *et al.*, 2001b; Kondaih *et al.*, 1985
Beef trim then ground beef			
Hot water/cold water	*E. coli* Coliforms *S. typhimurium* APC	0-2.4 0.1 0-2.0 0.1-1.1	Stivarius *et al.*, 2002a; Ellebracht *et al.*, 1999; Dorsa *et al.*, 1998a
Lactic acid	*E. coli* Coliforms *S. typhimurium* APC	0.1-2.9 0.7 0.2-3.2 0-0.6	Stivarius *et al.*, 2002a; Conner *et al.*, 1977; Dorsa *et al.*, 1998a
Acetic acid	*E. coli* Coliforms *S. typhimurium* APC	0.1-2.8 1.3 1.5-2.8 0.1-1.3	Stivarius *et al.*, 2002b; Conner *et al.*, 1977; Dorsa *et al.*, 1998a

Table 1 (continued). Selected postharvest interventions for beef tissue, cuts or in ground beef.

Antimicrobial	Microorganism	Inhibition (logs)	Reference
Gluconic acid	*E. coli* Coliforms *S. typhimurium* APC	0.3 0.2 0.1 0.5	Stivarius *et al.*, 2002b
Trisodium citrate	*E. coli* Coliforms *S. typhimurium* APC	0.1 0.1 0.2 0.2	Stivarius *et al.*, 2002b
Chlorine dioxide	*E. coli* Coliforms *S. typhimurium* APC	0.7 0.6 0.6 0.7	Stivarius *et al.*, 2002c
Ozone	*E .coli* Coliforms *S. typhimurium* APC	0.1 0.2-0.4 0.5-0.8 0.3-0.6	Stivarius *et al.*, 2002c
Trisodium phosphate	*E. coli* Coliforms *S. typhimurium* APC	0.8-2.3 0.7 0.7-3.1 0.6-0.7	Pohlman *et al.*, 2002b; Dorsa *et al.*, 1998a; Dorsa *et al.*, 1998b;
Cetylpyridinium chloride	*E. coli* Coliforms *S. typhimurium* APC	0.6 0.6 0.7 0.6	Pohlman *et al.*, 2002b
Multiple interventions	*E. coli* Coliforms *S. typhimurium* APC	0.6-2.6 0.4-1.9 0.3-2.0 0.3-1.8	Pohlman *et al.*, 2002a; Pohlman *et al.*, 2002c;
Ground Beef - Direct			
Sodium lactate	*E. coli* APC	Delayed growth 0-0.8	Ajjarapu & Shelef, 1999; Harmayni *et al.*, 1991; Maca *et al.*, 1997; Eckert *et al.*, 1997
Sodium diacetate	*E. coli* APC	Delayed growth Delayed growth	Ajjarapu & Shelef, 1999
Sodium acetate	APC	0.1-0.6	Maca *et al.*, 1997
Buffered citrate/Sodium citrate	APC	0-0.2	Maca *et al.*, 1997
Potassium lactate	Coliforms APC	0.5-1.0 0.1-0.8	Egbert *et al.*, 1992
Hydrostatic pressure	*E. coli*	~2.2	Carballo *et al.*, 1997

Multiple interventions evaluated are many including two or more combinations of heated mediums, organic acids, buffers, quaternary ammonia like mediums and oxidizers.
"~" symbol means that reductions were approximated.

Table 2. Selected postharvest interventions for poultry, pork and lamb whole muscle or comminuted products.

Item	Antimicrobial	Parameter	Microorganism	Inhibition (logs)	Reference
Chicken carcass	Acidified sodium chlorite and citric acid spray	1,100 ppm sodium chlorite 9,000 ppm citric acid	*E. coli* *Salmonella ssp.* *Campylobacter spp.*	2.3 *2.0* 2.6	Kemp et al., 2001
Chicken carcass H_2O prewash- (PR)	Acidifed Sodium Chlorite- ASC (A) Phosphoric (P) or Citric (C) activated Dip or spray	500-1,200 ppm ASC	E. coli Coliforms *Aerobic*	<u>Phos. activated</u> E coli- .72 Coliforms 1.51 Aerob- .72 <u>Citric activated</u> E coli ~ 2.3 Coliform ~.8-2.0 Aerob ~ .7-1.0	Kemp et al., 2000
Chicken carcass	Trisodium phos. (TSP) Lactic acid (L) Cetlypyridinium chloride (CPC) Sodium Bisulfate (SB)	TSP-10% L- 2.0% CPC- 0.5% SB- 5.0% spray	*Salmonella typhimurium* Aerobes	TSP- .74-4.87 L-1.03- 1.77 CPC- 0.9-2.3 SB- 1.66	Yang and Slavik, 1998, Lillard, 1994, Wang et al., 1997; Breen et al., 1997; Xiong et al., 1998; Kim and Slavik, 1996
Chicken wings	Lactic acid Sodium benzoate Wash (dip)	0.5% lactic 0.05% sodium benzoate	*Salmonella ssp.* *Campylobacter spp.* *L. monocytogenes* *S. aureus* *E. coli*	2.5 1.0 0.5 1.5 1.25	Hwang and Beuchat, 1995
Ground chicken	Hydrostatic pressure	0-700MPa	*Listeria* Salmonella *E. coli* *S. aureus*	Up to ~ 1.7-7.5 Up to ~ 2.0 Up to ~ 5.7-6.0 *Up to ~ 5-6*	Patterson et al., 1995, Patterson et al., 1998, Yuste et al., 1999
Meat models	Hydrostatic pressure	500MPa	*E. Coli, Staph spp., Listeria*	1.3-5.54	Hugas et al., 2002
Turkey Breast, core 10 days	Sodium lactate (SL) Sodium diacetate (SD)	SL- 2.0% SD- .1% SL+SD- 2.0%+.1%	*Clostridium spp.*	SL- 0.2 SD- .85 SL+SD- 0.8	Kalinowski and Tomkin, 1999
Ground turkey from RTE turkey breast	Sodium diacetate (D) Sodium nitrate (N) Sodium lactate (L) Pediocin (P)	D = 0.5, 1.0, 3.0% N = 30 ppm L = 2.5% P = 5000 AU/ml	L. monocytogenes	N+0.5%D- 3.41 L+0.5%D- 4.9 0.5%D- 4.96 P+0.5%D- 6.62	Schlyter et al., 1993
Pork Rib and Loin Chops	Acetic acid (A) Proprionic acid (P) Hypochlorite (H)	1.36M A+P 250 ppm H H+1ppb acetic acid sprays	Mesophilic bacteria	A+P - 0-1.0 H- 0- 0.1 H+A- 0.2-0.5	Carpenter et al., 1986
Pork Chops	Acetic acid- (A) Lactic acid- (L), dip	1% A 1% A+1.0% L	*Lactobacillus* *Enterobacters*	.1-.25 1.0-2.5	Mendonca et al., 1989
Pork Loins	Acetic acid Lactic acid Citric acid	1.5% A 1.5% L 1.5% C	Coliforms APC *E. coli*	A- 2.5, L- 0.5 A- 1.25, L- 0.0 A- 0.5, L- 0.1	Fu et al., 1994
Pork trim meat Cores (dip)	Lactic acid Hot water Hot air	Water + 2% L (WL) Water, HA, + L- (WHL)	*Aerobic* *Coliforms* *E. coli*	WL- 3.0, WHL- 2.0 WL- 2.25,WHL- 2.2 WL- 2.0, WHL- 2.0	Castelo et al., 2001
Lamb Carcass Muscle cores	Acetic acid	1.5 or 3.0%, Dip or Spray	*B. thermosphaeta* Aerobic Coliform	B.T. - 2.5 log 3% dip No other trt effects	Anderson et al., 1988
Sheep Subcutaneous	Hot water	Spray	Salmonella spp. *E. coli*	4.0 log 4.0 log	Smith andGraham, 1978

For pork, a number of postharvest decontamination studies have been performed on various pork loin chops. Using acetic acid on pork loin chops, reductions in various bacterial populations have been reported from 0-2.5 logs (Carpenter *et al.*, 1986; Mendonca *et al.*, 1989 and Fu *et al.*, 1994). Reductions in microorganisms on pork loin chops have also been reported for 0-2.5 logs with lactic acid used singly or in combination with acetic acid (Mendonca *et al.*, 1989 and Fu *et al.*, 1994). In other work, Castelo *et al.* (2001) was able to reduce APC, coliforms and *E. coli* by 3.0, 2.3 and 2.0 logs, respectively on pork meat trim using water and a 2% lactic acid treatment.

Although much limited in the body of research on lamb postharvest interventions, a few studies have been conducted. While Anderson *et al.* (1988) was able to reduce *B. thermosphaeta* on lamb muscle cores by 2.5 logs using a 3.0% acetic acid dip, they reported no reductions in APC or coliforms with acetic acid treatment. However, Smith and Graham (1978) reported 4.0 log reductions of both *Salmonella spp.* and *E. coli* on sheep subcutaneous tissue using hot water.

While the technologies discussed previously represent a cross-section of intervention technologies that have been researched, there are still a number of additional technologies with antimicrobial properties for reducing microbial loads on or within meat products. Examples of these might be hydrogen peroxide, pulsed light, copper sulfate pentahydrate, ultraviolet light, x-rays and irradiation to name a few. While a number of these technologies might hold promise for postharvest pathogen reductions and interventions, because of the infancy of postharvest research, the regulatory status for use of a number of these technologies has not caught up to the science. While a number of these technologies have been approved for carcass decontamination applications, less have been approved for postharvest pathogen reduction. While some interventions have been approved and commercialized for use such as the use of ozone, a chlorous acid system and a peroxyacid system, others await regulatory approval. In addition to approval and microbial reduction effectiveness, other issues for technology adoptions include the impact of postharvest pathogen reduction technologies on processing characteristics, color, shelf-life and sensory characteristics. While occasionally research has addressed these concerns, the largest body of information remains on antimicrobial effectiveness alone. Therefore, as more interventions are approved for postharvest applications, additional research will be necessary to answer processing and quality issues.

Conclusions

While substantial research has been conducted using antimicrobials for carcass decontamination, it is only more recently that research has begun to focus upon postharvest pathogen reduction. Although intervention technologies have led to declines in microbial loads on carcass surfaces, since these technologies do not render the carcass sterile, processing contamination of cut surfaces can occur when carcasses are fabricated due to contamination through meat contact with knives, conveyors, human hands etc. Therefore, the use of postharvest interventions may offer an additional pathogen reduction that might benefit the consumer directly in the package. Additionally, since ground beef can be of special concern with regard to meat safety, the use of these intervention technologies might also hold promise for reducing microorganisms and pathogens in this product. However, using the multiple intervention approach, the greatest benefits might be achieved with concerted intervention strategies at several steps through the processing chain.

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