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Integrating microbial decontamination with organic acids in HACCP programmes for muscle foods: prospects and controversies

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Abstract

A considerable literature reports the antibacterial efficacy of dilute solutions of organic acids (lactic, acetic). With carcasses an overall reduction in surface contaminants of 1.5 log cycles can be expected. Carcass decontamination may not improve the safety of the resultant meat, but laboratory trials confirm that acid decontamination of subprimal and retail cuts is more efficacious. An advantage over many other intervention strategies is that residual antimicrobial activity is demonstrable over extended periods of storage. These studies have also shown that some meatborne pathogens are particularly sensitive to organic acids (i.e., *Yersinia enterocolitica*) while others are resistant (i.e., *E. coli* 0157:H7). Dilute solutions of organic acids (1 to 3%) are generally without effect on the desirable sensory properties of meat when used as a carcass decontaminant. However, dependent on treatment conditions, lactic and acetic acid can produce adverse sensory changes when applied directly to meat cuts, with irreversible changes in appearance being a frequent occurrence. It is speculated that organic acid decontamination will be implemented in American abattoirs in an effort to meet specified performance standards for pathogen reduction as part of an overall HACCP program. In contrast, the EU advocates that strictly controlled processing hygiene is sufficient to ensure the safety of the product. Additional research is necessary to establish a set of treatment conditions that may permit a practicable reduction in bacterial contamination throughout the processing chain with a measurable effect on safety and storage life, without imposing any change in sensory properties. It will also be necessary to develop standard, objective measures to assess HACCP and the efficacy of decontamination procedures. Without such commercial studies controversy on the practicality of acid decontamination will persist. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The possibilities for eliminating pathogenic micro-organisms from meat has received considerable attention in recent years. Ten years ago a group of international experts considered an integrated approach to the problem with assessment of efficacies of various separate or combined production practices

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or product treatments (Smulders, 1987). The consensus was that strict adherence to measures of Good Farming Practice and Good Manufacturing Practice during production and processing should be the basis of muscle food safety strategies, and that decontamination steps of whatever nature should serve as only supplementary means of assuring safety. Since then, the decontamination issue has been extensively studied by microbiologists, process engineers and public health officials. Recently, an overview of various methods of meat decontamination was prepared in the UK (James et al., 1997). Among the technologies considered, the use of organic acids was identified as one of the most practical options. Also, the use of organic acids as a decontaminant in North American abattoirs has been recommended (USDA, 1996).

In spite of the efforts to provide information on acid decontamination, and the advocation of acid decontamination by some, public health officials in some parts of the world remain uncertain as to its permissibility. Part of this attitude is unrelated to science and the current friction between major political factions, which largely result from reluctance to implement WTO agreements, will inevitably lead to renewal of the argument. It seems timely, therefore, to once again consider the pros and cons of the issue, on the basis of only scientific data, especially those generated during in-plant tests and with particular reference to the situation in Europe and North America.

2. Scope of the problem

Despite an abundance of research on the antimicrobial efficacy of organic acids there is a dearth of data on these effects in commercial practice. Thus, most studies have been conducted in research abattoirs and/or with artificially-inoculated carcasses, cuts or small portions of meat tissue. The results of these studies have been adequately summarized in comprehensive reviews over the past 20 years (Smulders, 1987, 1995; Siragusa, 1995).

Table 1 is an attempt to summarize the major findings on the antimicrobial actions and sensory effects of organic acids and how these are affected by slaughter technologies and other decontamination techniques.

To extrapolate the results of laboratory or pilot plant studies to commercial processes is not legitimate as it is difficult to predict the practical impact of carcass acid sprays on the safety and storage quality of the resultant meat. The danger in speculating on the basis of laboratory trials has recently been summarized by Dorsa et al. (1997) who concluded: ‘‘The large differences among the results of the many laboratory studies and the actual industrial practices of applying organic acids and/or antimicrobial agents indicate the inappropriateness of extrapolating’’.

It is the intent of the current overview to compare the results of laboratory and commercial trials from the perspective of red meat safety, spoilage and sensory changes and to evaluate the future role of organic acid treatments in the HACCP systems which will be implemented in north American abattoirs during the next year or two.

3. Current commercial use

The use of organic acids for meat decontamination is not practised widely. Within the European Union (EU), meat hygiene regulations do not allow any method of product decontamination other than washing with potable water. The major reason for this is the reluctancy of legislators to grant permission for the adoption of this technology, as it is perceived to be a means of concealing or compensating for poor hygienic practices in the slaughterhouse. The EU’s advisory Scientific Veterinary Committee recently issued a Report (EU, 1996) in which the desirability of decontamination using irradiation, organic acids, alkaline compounds such as trisodium phosphate, hyperchlorinated water, or steam or hot water was evaluated. Use of such treatments for poultry carcasses only was considered, as the view generally persists that in the processing of the other major meat species adherence to strict hygiene measures will suffice to avoid major problems. Table 2 includes the criteria as formulated by this group that must be met before decontaminating compounds may eventually be considered for acceptance in poultry processing.

Despite regulatory approval it is evident that organic acid decontamination has not found acceptance or been widely applied in commercial practice,

Table 1
Major considerations in the selection of organic acids as meat decontaminants (after Smulders, 1995)

1. Antimicrobial effects of acids are

(a) Acid-dependent
- pH (acid concentration)
- Intracellular dissociation of the acid (pH-dependent)
- Specific anion effect:
  determines the ability to penetrate the bacterial cell
  related to targets within the cell and chemical nature of attack
- Acid mixtures (affecting extent of dissociation and possible mutual potentiation)

(b) Tissue-dependent
- Meat species (nature of the meat surface)
- Buffering capacity (lean greater than fat)

(c) Bacterial-dependent
- Sensitive: e.g., *Campylobacter jejuni*, *Yersinia enterocolitica*, Pseudomonads
- Resistant: e.g., *Escherichia coli*, *Listeria monocytogenes*

(d) Slaughter technology-dependent:
- Degree of initial microbial contamination
- Nature of contaminating material (organic matter content)

(e) Decontamination technique-dependent
- Time of acid application
- Contact time with acids
- Temperature of acid sprays
- Spray pressures, spray angles
- Method of application

2. Sensory effects

(a) Colour
- Grey–brown fat discoloration
- Bleaching of the lean

(b) Flavour/odour
- Occasionally vinegar-like off-flavour/off-odours when using acetic acid
- Sensory scores rarely affected by lactic acid at effective concentrations

(c) Water-holding
- Drip loss increase in comminuted meats, particularly after immersion in acids

Table 2
Factors for consideration in the application of decontaminants (proposed by the Scientific Veterinary Committee of the EU, 1996)

Chemical composition and properties, e.g., pH, water and fat solubility, mode of action
Safety aspects: is it an approved food additive or a GRAS (generally recognized as safe) compound?
Residues in the decontaminated product
Impact on the product with regard to organoleptic quality (taste, appearance, etc.)
Nutritional value
Risk of formation of toxic compounds
Water retention properties
Effect on pathogenic and spoilage organisms; possible implications of flora changes
Impact on spoilage and shelf life
Relationship between the number of pathogens and the desired effect
Staff health aspects including hypersensitization
Recycling, recovery and environmental impact
Microbial investigations in situ to prove efficacy
Method of application and concentrations to be used
‘‘Food additive’’ or ‘‘processing aid’’?

even in North America. In Canada, the use of lactic and acetic acid sprays as a ''processing aid'' has been approved as an adjunct to good manufacturing practices during the carcass dressing process. Within this context, there was some initial concern that organic acids may be utilized as a terminal treatment to mask spurious hygienic processing practices. Application for approval to use acids is tedious and must include meeting numerous requirements with respect to facilities, equipment and evidence of a quality control program including the specification of steps within such a program. In view of the complexity of this documentation, it is understandable that this technology has not been adopted by the Canadian industry.

Within the United States, lactic and acetic acids have GRAS status and are approved for use. It is likely that American abattoirs were the first to incorporate organic acid sprays as a component of the carcass dressing process. In fact, Canadian regulatory authorities approved the importation of American beef from acid-treated carcasses long before approval for use of acids in Canadian abattoirs. Siragusa (1995) concluded that low concentrations of acetic acid are used to a limited extent in abattoirs in the United States.

Organic acid decontamination systems have been utilized in an Australian export beef plant but their use has been discontinued this year due to the corrosion of meat processing equipment (Barry Johnson, 1997, Australian Meat Technology, Personal Communication).

4. Commercial trials

In this review, the term ''commercial trial'' will refer to research conducted in an abattoir or packing plant operated in the private sector, under normal conditions of operation and with carcasses contaminated with indigenous bacterial populations. This necessarily excludes studies undertaken in research abattoirs or pilot plant studies with artificially-inoculated carcasses or meat. Although this definition may be considered restrictive, and investigations of this nature are rare, it is data collected from such commercial trials that will be the ultimate test of practical value.

Commercial efficacy data are derived with the use of either of two types of acid application equipment. Those are hand held, portable misters or automated, carcass sanitizers incorporated into the dressing process. The results of in-plant trials with the former mode of application have demonstrated that organic acids can effect a 1 to 2 log reduction in the total aerobic bacterial population on the surface of pork (Biemuller et al., 1973) and beef (Prasai et al., 1991) carcasses. These latter researchers compared the bacterial efficacy of a 1%, 55°C lactic acid spray in slaughter plants differing in size. Post-acid treatment and immediately following entry into the cooler, the mean log reduction in carcass surface contamination was 1.8 for a small slaughter facility (125 head/day) and 1.9 for a large slaughter facility (1250 head/day).

Although the method employed was not apparent, the results of a more recent study were contrary (Avens et al., 1995). These researchers examined the decontamination of beef carcasses using a 1% acetic acid spray over a 61 week interval in two processing plants. It was found that the treatment was ineffective in reducing contamination to levels below that observed in control plants. These carcasses were reported to be contaminated with comparatively low levels of bacteria and this could account for the disparity of results (Smulders and Woolthuis, 1983).

The in-plant evaluation of automated beef carcasses sanitizing units has been described (Anderson et al., 1980, 1987). This type of cleaning/sanitizing apparatus was able to produce a 1.5 log reduction in bacteria on carcasses when 3% acetic acid was used as the sanitizing agent. Others have also described the manufacture of stainless steel spray cabinets that can be incorporated into meat production lines (Brammall, 1994) and it has been estimated that the cost of spraying pork carcasses with acetic acid would be 0.015 to 0.03 $US per head.

Smulders (1995) has developed and described in detail the operation and performance of a prototype carcass washer for veal slaughtering plants. Results of a preliminary commercial evaluation showed that 2% lactic acid produced a 1.5 log reduction in the numbers of bacteria recoverable from the carcass surface.

There are reports that the treatment of commercially processed carcasses with organic acids can reduce the incidence of human pathogens (Epling et al., 1993), but others have found no consistent effects upon psychrotrophic or mesophilic pathogens (Fu et al., 1994).

One of few known studies to trace the efficacy of commercial, carcass sanitizing treatments through to retail cuts was published by Fu et al. (1994). Although the storage quality of vacuum packaged loins and the case life of retail cuts was evaluated under laboratory conditions, the carcasses were treated with 1.5% acetic, citric or lactic acid following in-plant slaughter and immediately before entry into the carcass cooler. These treatments produced negligible bacteriostatic effect with pork loins and no differences in the retail case life of chops from control or acid-treated carcasses could be determined.

There are no known published results of commercial trials to evaluate organic acid decontamination of subprimal or retail cuts. With the possibility of treatments to reduce acid mediated discolouration it may be a more reasonable approach as opposed to carcass decontamination. Another alternative would be intervention at two points in the process (i.e., carcass and subprimal level) as described by Smulders and Woolthuis (1985). With centralized production systems on the horizon this approach may integrate best with HACCP systems of the future.

In summary, data collected from commercial efficacy trials with organic acids show that an average 1.5 log reduction in total aerobic bacteria recovered from carcass surface would be expected with an uncertain impact upon the incidence of human pathogens. In consideration of the corrosive potential of the acids, claims of undesirable sensory changes in meat quality and commercially viable alternatives, some question the value of continued research in this area. Thus, a hot water pork carcass pasteurizer currently in use in a Canadian abattoir operating at a line speed of 1200 carcasses/h has been shown to reduce carcass total counts, coliform and *Escherichia coli* by about two-orders of magnitude (Gill et al., 1997). More recently, Gill and Bryant (1997) have determined that a combined treatment of beef carcass steam pasteurization and chilling can eliminate *E. coli* from carcass surfaces in a beef processing plant operating at a line speed of 280 carcasses per hour.

5. Meat model systems

Data on the antibacterial efficacy of organic acids have been compared in overviews that span the literature from 1979 to 1995 (Smulders et al., 1986; Dickson and Anderson, 1991; Smulders, 1995; Siragusa, 1995). As noted by Siragusa (1995) these efficacy data have been primarily generated from laboratory trials and the considerable variability in results can be related to differences in experimental design.

This review will consider the results of experimental trials involving naturally-contaminated or artificially inoculated carcasses, cuts or excised tissues.

5.1. Carcasses

The concept of ‘‘intervention’’ to control meat-borne disease was introduced by Mossel (1984). He opined that hygienic processing and controlled food service practices were not sufficient to control the agents of enteric infections and a third line of defense i.e., organic acid decontamination was proposed. In recent years, increasing numbers of *E. coli* 0157:H7 outbreaks prompted regulatory authorities to mandate requirements to control the meat carcass dressing process with a view to reduce contamination with enteric pathogens. Thus, HACCP will be a regulatory requirement in North America abattoirs, and ‘‘intervention’’ strategies have been recommended. Carcass intervention procedures such as washing, sanitizing agents, pasteurization are perceived as a complement to HACCP to improve the bacterial condition of the carcass by intervention at specific points in the process (Prasai et al., 1995; Hardin et al., 1995; Siragusa, 1995; Gorman et al., 1995a; Dorsa et al., 1996a; Gorman et al., 1997; Phebus et al., 1997).

The objective of this overview will be to consider the more recent data on organic acid decontamination within the context of an HACCP program which is rapidly becoming a commercial reality. Organisms of specific interest to regulatory authorities are *E. coli* and *Salmonella*.

Recent pilot plant studies with implications for HACCP systems have employed models involving the inoculation of carcass surfaces with faecal suspensions. It is clear that these studies do not reflect the efficacy of organic acid decontamination under practicable commercial circumstances but they do provide insight into the susceptibility of specific pathogens inoculated onto carcass surfaces.

The research of van Netten et al. (1995) supported the recommendations that a 30-s treatment of pork carcass surfaces with 2% lactic acid could reduce inoculated *Salmonella typhimurium* to below detectable levels and would, therefore, constitute an intervention that could be incorporated into a HACCP system.

Using a similar approach, Hardin et al. (1995) evaluated decontamination of beef carcass surfaces inoculated with suspensions containing *E. coli* 0157:H7 and *S. typhimurium*. Treatment with a 2% organic acid spray (lactic or acetic) significantly reduced those pathogens at the site of faecal inoculation. Also of importance, the treatments were able to reduce bacterial contamination spread to previously uncontaminated sites by an initial water rinse. It was observed that a water wash/acid treatment was more effective in reducing pathogens over the entire carcass surface in comparison to localized trimming of visibly contaminated sites. Thus, these investigators concluded that organic acid rinses would be of value as a critical control point in a HACCP system.

A most important consideration in the advocation of an organic acid intervention strategy as a component of HACCP is the common North America practice of spray-chilling (Greer and Jones, 1997). During this process, dressed carcasses are subjected to a water spray mist at timed cycles during the initial 3 to 12 h of carcass chilling to prevent evaporative weight losses. It is conceivable that the antimicrobial effects of the organic acid treatments would be diluted in this considerable volume of water deposited on the meat surface. To investigate this premise, Dickson and Anderson (1991) used a series of simulated spray-chilling cycles in conjunction with 2% acetic acid to confirm that inoculated *Salmonella* could be reduced by as much as 2 log cycles by alternating water and acid spray treatments but this remains to be validated in commercial trials. It was noteworthy that these researchers observed that water spray-chilling enhanced the recovery of acid-injured *Salmonella*, a finding which is critical to a regulatory philosophy in which *Salmonella* reduction is a target of the mandatory performance standard.

In studies with red meat carcasses the usual approach has been to determine the immediate reduction in indigenous bacterial contamination in pilot plant studies. Over the past 20 years results have repeatedly confirmed that an average reduction in the aerobic plate count approximating 1.5 log cycles would be expected. Unfortunately, this decontamination procedure has not assured the safety of vacuum packaged primals or retail cuts derived from treated carcasses (Greer and Jones, 1991; Prasai et al., 1991, 1992; Kenney et al., 1995; van Netten et al., 1995; Siragusa, 1995). In accordance with the views of van Netten et al. (1995) the critical issue is the impact of organic acid treatment on the safety of meat destined for consumption by the consumer and this risk has yet to be ascertained.

5.2. Meat cuts

It is of relevance that in current regulatory thinking, implementation of HACCP systems and setting of performance standards are conceived as primarily involving carcass dressing processes. Also, carcass decontamination is a fixed point intervention and recontamination during carcass breaking and further processing is inevitable. It would seem of greater value to apply a treatment such as organic acid decontamination at the level of the subprimal or retail cut, but data on the treatment of such product are limited and there appears to be an increased risk of detrimental sensory changes.

A number of researchers have examined the combined effects of vacuum packaging and organic acid decontamination on bacterial and storage life for storage intervals varying up to 112 d for pork loins (Cacciarelli et al., 1983; Shay et al., 1988), beef (Zepeda et al., 1994a; Goddard et al., 1996), lamb loins (Gill and Penney, 1985) and veal (Smulders and Woolthuis, 1985). Residual effects were recently noted by Prasai et al. (1997) who reported that the pronounced antibacterial effects of lactic acid in limiting the growth of bacteria on vacuum packaged strip loins were augmented at colder storage temperatures.

In most instances bacterial growth was restricted and storage life enhanced but there was no information on the growth and survival of enteric pathogens. A notable exception was research published by Smulders and Woolthuis (1985). These researchers reported a reduction in total enterobacterial counts and *Salmonella* on hot-boned, vacuum packaged veal muscle decontaminated with 2% lactic acid.

It has also been proposed that hot-boning and acid decontamination may be a suitable technology for developing countries where slaughter, transport and chilling is hygienically inadequate (Mathieu and Van Hoof, 1992a,b, 1993). A combined hot-boning/acid spray regime reduced *Salmonella* on deboned beef and could provide an economically feasible alternative to traditional, cold-boning systems in the tropics.

A more recent study in which large portions of excised carcass muscle tissue was subjected to a lactic acid spray also compared this treatment to other intervention strategies from a practical perspective (Phebus et al., 1997). These investigators found that a combined treatment of multiple decontamination procedures (trimming, water wash, lactic acid spray, steam pasteurization) was most efficacious in reducing *S. typhimurium*, *E. coli* 0157:H7 and *Listeria monocytogenes* artificially inoculated onto *Cutaneous trunci* muscle. Caution was advised in the use of organic acid sprays and dips for the decontamination of carcasses in commercial abattoirs due to resistance of some bacterial groups, the potential to corrode equipment, creation of unfavorable working environments and effects upon the subsequent treatment of waste water.

There have been limited reports of laboratory trials where organic acids have been applied directly to retail product in an effort to reduce indigenous microbial populations. Such studies have shown an increased storage life of veal tongues (Visser et al., 1988), and minced beef (Niemand et al., 1983), and the control of *L. monocytogenes* on the surface of frankfurters (Palumbo and Williams, 1994).

Studies with retail beef steaks have been inconclusive. Thus, Dixon et al. (1991) sprayed beef strip loin steaks with acetic and lactic acids or mixture containing citric and ascorbic acids and found no difference in sensory properties or bacterial condition in comparison to control steaks. In contrast Kotula and Thelappurate (1994) reported a significant reduction of *E. coli* on rib-eye steaks treated with an acetic acid dip.

As emphasized throughout this review, discolouration (Kotula and Thelappurate, 1994; Niemand et al., 1983) continues to be a problem associated with organic acid decontamination of cuts. Before it can be prescribed as a practicable intervention to improve safety considerably more research must be undertaken to establish treatment conditions to maximize safety while minimizing sensory deterioration.

5.3. Meat tissue models

Research concerning the antibacterial efficacy of organic acids at artificially inoculated surfaces of excised fat and muscle tissue is abundant and has been reviewed (Smulders, 1995; Siragusa, 1995). It is clearly not possible to extend results with model systems using unrealistically high levels of inocula (10^5–10^7) to practical circumstances of application under commercial conditions where pathogen levels are small (< 10). However, models are of value in rapidly screening the susceptibility of meatborne bacteria to organic acids and in establishing treatment conditions that would optimize bactericidal potential. Models are also useful in providing a fundamental understanding of the interaction of organic acids with the bacterial cell and the mode of action of acids. Thus, there are considerable data that have been published from research conducted at the University of Missouri (Anderson and Marshall, 1989, 1990; Anderson et al., 1977, 1992) and Dickson and co-workers at USDA, Clay Centre (Dickson, 1990, 1991, 1992b; Siragusa and Dickson, 1993) which has resulted from an evaluation of factors affecting the bactericidal effects of organic acids.

More recently, van Netten and associates (van Netten et al., 1994a,b) have developed and applied an in vitro model to assess factors influencing the bactericidal efficacy of lactic acid. It was concluded that a 2% solution of lactic acid at 37°C for 30 to 90 s would eliminate *Salmonella* but not *L. monocytogenes* in pork skin suspensions.

Mathematical models have also been formulated to predict the effect of variables upon the interaction of organic acids with *Staphylococcus aureus* (Eifert et al., 1997), *L. monocytogenes* (George et al., 1996) and *Yersinia enterocolitica* (El-Ziney et al., 1997).

There has been concern that decontamination with organic acids could result in the emergence of meatborne pathogens that have become acid tolerant. The role of environmental factors in influencing acid sensitivity and tolerance in enterobacteria has been reviewed (Rowbury, 1995). Of more relevance to the meat environment, the resistance of acid-adapted *Salmonella* to lactic acid rinses has been examined using artificially-inoculated beef muscle slices (Dickson and Kunduru, 1995). The results showed that acid-adapted strains were not more resistant to acid decontamination than parental strains. The more current research of van Netten et al. (1997) showed that low temperature and acid-adapted *Y. enterocolotica* and *L. monocytogenes* did not constitute an increased health risk.

Generally, mesophilic enterobacteria are among the most resistant to organic acids in comparison to other pathogens. The data in Table 3 show the effect of 3% lactic acid on the aerobic growth of a clinical isolate of *E. coli* 0157:H7 on beef muscle. At a solution temperature of 20°C, a 3% concentration of lactic acid was without effect upon *E. coli* 0157:H7. When solution temperatures were increased to 55°C, lactic acid could effect a reduction of about 1 log cycle from a $\log_{10}$ CFU/cm^2 of about 5 to a log CFU/cm^2 of about 4 but a reduction of this magnitude would not provide any assurance of safety.

The data in Table 4 provide a comparison of studies on the susceptibility of *E. coli* 0157:H7 to organic acids. Results generally show limited efficacy with reduction of less than 1 log cycle with the exception of research incorporating a pilot scale washer where the observed decreases in the population of inoculated *E. coli* 0157:H7 were 1 to 2 log cycles (Cutter and Siragusa, 1994).

Similar data are available for *Salmonella* (Table 5). In comparison to *E. coli*, *Salmonella* may be more sensitive to the lethal effects of organic acids in that acid-mediated reductions of greater than 1 log cycle would seem more probable.

The unusual resistance of *E. coli* 0157:H7 may be related to some inherent property of the organism itself or to the nature of the attachment of *E. coli* to

Table 3
Effect of lactic acid on the growth of *E. coli* 0157:H7 on lean beef[a,b]

Aerobic storage time at 4°C (d)	Log CFU/cm^2			
	20°C		55°C	
	Control	3% Lactic	Control	3% Lactic
0	5.62	5.62	5.62	5.62
1	4.98	5.20	5.53	4.35
4	5.03	4.81	5.48	4.26
7	5.05	4.96	4.92	3.88
11	4.68	4.34	4.38	4.00

[a] *E. coli* 0157:H7 ATCC 43895.
[b] Inoculated, sterile beef muscle discs were dipped in a solution of 3% lactic acid for 15 s at a solution temperature of 20 or 55°C. Greer and Dilts, 1995 (unpublished).

Table 4
Comparison of the decontamination of meat inoculated with *E. coli* 0157:H7

Tissue	Method	Effect	Ref.
Lean beef	2% lactic dip 2% lactic and alginate dip	0.50 log reduction 0.74 log reduction	Siragusa and Dickson, 1993
Lean beef and adipose	1, 3, 5% lactic, acetic, citric pilot scale washer	1 to 2 log reduction	Cutter and Siragusa, 1994
Lean beef	1.5% acetic, lactic spray, 20 or 55°C	0.3 to 0.5 log reduction	Brackett et al., 1994
Lean beef	1% lactic 1% acetic 1.5% fumaric dip	0.78 log reduction 0.63 log reduction 1.96 log reduction	Podolak et al., 1995
Lean beef	3% lactic dip, 20°C 3% lactic dip, 55°C	0.34 log reduction 1.22 log reduction	Greer and Dilts, 1995 (unpublished)
Beef tenderloin and adipose	2% acetic rinse	No effect	Fratamico et al., 1996

Table 5
Comparison of the decontamination of meat inoculated with *Salmonella typhimurium*

Tissue	Method	Effect	Ref.
Beef semitendinosus	1–3% lactic dip, 25 to 70°C	1 log reduction	Anderson and Marshall, 1990
Beef lean and fat	2% acetic vortex	50% reduction on lean 80–90% reduction on fat	Dickson, 1992a
Beef lean and fat	2% acetic, vortex	0.5 to 0.8 log cycles reduction	Dickson, 1992b
Lean beef	3% acetic, lactic	0.4 to 1 log cycle reduction	Greer and Dilts, 1992
Beef, lean and fat	2% acetic vortex	0.6 to 0.8 log cycles reduction	Dickson and Frank, 1993
Pork cheek meat	2% acetic spray, 20°C	2 log cycles reduction	Frederick et al., 1994
Beef round	3% lactic vortex, 23 and 55°C	1.0 log cycle reduction	Dickson and Kunduru, 1995

meat tissues. Thus, attached bacteria have been reported to be more resistant to sanitizing agents. In studying the effects of rinsing agents on the attachment of *E. coli* 0157:H7 to beef, Fratamico et al. (1996) suggested that binding to collagen may be a mechanism of attachment. Once attached, rinsing with 2% acetic acid was not effective in removing *E. coli* or reducing the level of surviving *E. coli* at beef surfaces.

Efficacy data must be carefully interpreted with consideration of appropriate controls. Thus, the data in Table 6 compare the efficacy of acid or water spray washes in removing *E. coli* 0157:H7 from beef tissue artificially inoculated with bovine feces. It is often the case that water alone can effectively remove populations of a magnitude similar to that observed when lactic or acetic acids are incorporated into the rinse.

In view of the preceding, it is of interest that proposed mandatory performance standards promulgated by the United States Food Safety Inspection Service (likely to be emulated in Canada) include *Salmonella* and *E. coli* as organisms of primary concern. HACCP-based systems will likely include generic *E. coli* as an objective means of verification. In accordance with the conclusions of Anderson and

Table 6
Decontamination of meat inoculated with *E. coli* 0157:H7[a]

		Reduction (log CFU/cm^2)		
Tissue	Acid	Water	Acid	Ref.
Beef brisket	2% acetic or lactic spray	3.0 3.0	3.0 4.2	Hardin et al., 1995
Beef short plates	3% acetic or lactic spray	1.7 1.7	2.7 2.7	Dorsa et al., 1997
Beef cutaneous *trunci*	2% acetic spray	2.8	3.0	Cutter et al., 1997

[a] Immediate effects.

Marshall (1989), the comparative resistance of *E. coli* to lactic acid may be an important factor in selecting this organism as a test organism in future studies of organic acid decontamination systems.

With the exception of lactobacilli (Ouattara et al., 1997) psychrotrophic meatborne spoilage bacteria (*Pseudomonas* spp., *Brochothrix thermosphacta*) and pathogens (*Listeria*, *Yersinia*, *Aeromonas*) are far more sensitive to organic acids than the mesophilic enteric pathogens (Greer, 1993; Greer and Dilts, 1995). In fact under optimal treatment conditions it is possible to reduce these psychrotrophic pathogens to below recoverable levels on fat tissue (Table 7). The data in Table 7 compare the sensitivities of three psychrotrophic pathogens (*L. monocytogenes*, *Y. enterocolitica*, *A. hydrophila*) on pork lean and fat. Depending upon species, a 3% solution of lactic acid produced a 6 to 7 log cycle reduction on fat and a 2 to 4.5 cycle reduction in bacteria inoculated on the surface of lean. Although these psychrotrophic pathogens are not targets for reduction by regulatory authorities they can grow and survive at meat storage temperatures and their response to sanitizing, intervention strategies should be given more serious consideration.

There have been some reports in which a number of spray-washing treatments have been compared using adipose tissue inoculated with a faecal paste seeded with *E. coli* (Gorman et al., 1995b; Cabedo et al., 1996; Gorman et al., 1997; Kochevar et al., 1996). These investigators observed that the magnitude of the antibacterial effects were similar with 74°C water or 2% acetic acid. It was further recommended that hot water sprays may be the most efficacious means of carcass decontamination while chemical sanitizers may be more effective at lower solution temperatures. In consideration of these data, one might question the wisdom of advocating chemical sanitizers when a 3 log cycle reduction in bacterial contamination can be achieved with hot water alone.

There are additional published data demonstrating that steam and hot water sprays can produce substantial reductions in bacterial populations (Dorsa et al., 1996a,b). Unfortunately, the bactercidal effects associated with these treatments are immediate and no residual activity is demonstrable. In this regard, Dorsa et al. (1997) reported that acetic or lactic acids could not produce greater initial reductions in total aerobic bacteria than water alone. However, when inoculated beef short plates were sprayed with organic acids, significant antibacterial effects were observed for up to 21 d of anaerobic storage, post-treatment. This delayed effect was confirmed for beef inoculated with *E. coli* 0157:H7, *L. innocua* and *Clostridium perfringens*. It is unfortunate that approved use of organic acids is restricted to carcasses and may not be utilized by the industry to decontaminate cut meat surfaces (Dorsa et al., 1997) where delayed antibacterial effects could be substantial.

Table 7
Effect of lactic acid on psychrotrophic pathogens inoculated on pork[a,b]

Bacteria	Maximum reduction ($\log_{10}$ CFU/cm^2)	
	Fat	Lean
Listeria monocytogenes	7.0	2.0
Yersinia enterocolitica	7.0	4.5
Aeromonas hydrophila	6.5	3.5

[a] Fat or lean cores were inoculated with the bacteria, dipped in 3% lactic acid at 55°C and stored for 7 d at 4°C.
[b] After Greer and Dilts, 1995.

6. Organoleptic/physical implications

There is no value in making improvements to meat storage stability and safety while compromising the desirable palatability and organoleptic attributes including flavour, texture, colour and odour. It is reasonable to assume that acids would have the potential to accelerate the oxidation of myoglobin and impart acidic odours or flavours but the literature abounds with disparity and this could be attributable to the extent of variability in treatments.

The effects of organic acids on the sensory properties of meat have been reviewed (Smulders et al., 1986; Smulders, 1987) and in a more recent comprehensive overview compiled by Smulders (1995) the effects of organic acids upon meat colour, odour and flavour were considered in detail. The results of that review supported the conclusion that decontamination of red meat carcasses with 1 to 2% lactic or acetic acid had limited effects upon the sensory quality of meat. It is evident that the often reversible discolouration of the carcass surface is not manifest in cuts prepared from acid decontaminated carcasses. However, the treatment of subprimal or retail meat cuts with acids can often be deleterious. The data in Table 8 summarize results of changes to the sensory properties of meat cuts following treatment with lactic or acetic acids or mixtures of the two acids. Although the findings are inconsistent it may be possible to identify a trend in relation to the mode of application of the acid. Thus, the most consistent pattern that emerges is that the immersion of meat cuts in acidic solutions tends to be more detrimental than decontamination by spray treatment. As evident in the Table, the application of organic acids by dipping cuts can result in discolouration, flavour defects and increased exudate.

An example of the effects of a lactic acid dip on pork lean colour reflectance is shown in Table 9. The data show that lactic acid produced increases in L^* and b^* values and usually decreased a^* values. Sensory panels recorded an undesirable grey/brown discolouration of the lean during aerobic storage post-treatment.

There have also been reports of changes in the microstructure of beef mediated by lactic/acetic acid treatment. A 2% lactic and acetic acid mixture produced a denaturation of myofibrillar proteins but this was without significant effect upon shear force (Mikel et al., 1996). In contrast, a 30 min dip with 0.5 M lactic acid decreased the amount of connective tissue and shear values in restructured beef steaks (Whiting and Strange, 1990).

It was of interest that lactic acid injection of fresh bovine muscle was found to accelerate conditioning (Stanton and Light, 1990) but this treatment did not alter the microbiological condition (Eilers et al., 1994).

In-plant trials would suggest that acids do not produce colour or flavour changes in pork (Brammall, 1994) or colour changes in beef carcasses (Prasai et al., 1991). However, Anderson et al. (1980) reported that a prototype carcass sanitizing

Table 8
Effect of organic acids on sensory properties of meat cuts

Cut	Treatment	Application	Sensory change	Ref.
Pork loin	2% acetic	Spray	Discolouration	Cacciarelli et al. (1983)
Beef steaks	1% acetic or lactic plus mix	Spray	No effect on odour or colour	Dixon et al. (1987)
Beef strip loins	1% acetic or lactic plus mix	Spray	No effect on odour or colour	Acuff et al. (1987)
Beef strip loins	2% lactic/acetic mix	Spray	No effect on colour, shear or cooking loss	Mikel et al. (1996)
Beef strip loins	2% lactic/acetic mix	Spray	No effect on colour or odour	Goddard et al. (1996)
Beef cubes	1.2% acetic	Dip	Flavour defect, discolouration	Bell et al. (1986)
Pork chops	1% acetic or lactic plus mix	Dip	Exudate increase, discolouration	Mendonca et al. (1989)
Beef steaks	2% lactic or acetic	Dip	Discolouration	Kotula and Thelappurate (1994)
Pork tissue discs	3% lactic	Dip	Discolouration	Greer and Dilts (1995)

Table 9
Effect of lactic acid on lean pork colour reflectance

Storage time	L^*		a^*		b^*	
(d)	Water	Acid	Water	Acid	Water	Acid
0	55.02	56.80	6.68	7.60	5.50	5.76
4	53.38	58.70	5.44	5.30	6.58	7.78
15	46.42	54.00	4.36	3.18	7.16	8.68

Meat discs were immersed in water or 3% lactic acid at 55°C.
CIE L^* (dark to light), a^* (green–red), b^* (blue–yellow) surface.
Reflectance values were measured after each interval of aerobic storage at 4°C.
Data are means of five replicates (Greer and Dilts, 1994).

unit employing 3% acetic acid resulted in slight but detectable off-flavours in treated beef fat.

Although there are no known reports of commercial application of organic acids at the subprimal or retail level there have been studies conducted to evaluate sensory changes in vacuum packaged subprimals and retail cuts following spray treatment of carcasses in commercial or research abattoirs (Acuff et al., 1987; Jeremiah et al., 1991; Zepeda et al., 1994a; Fu et al., 1994). On the basis of this research, there was no evidence that decontamination of pork or beef carcasses with organic acids produced objectionable changes in the colour, odour, flavour, moisture loss or cooking properties of the resultant meat.

In summary, dilute solutions of organic acids are generally without effect on the desirable sensory properties of meat when used as a carcass decontaminant. However, depending upon treatment conditions lactic and acetic acids can produce adverse sensory changes when applied directly to meat cuts, with irreversible changes in appearance being a frequent occurrence. This is unfortunate since decontamination of smaller meat portions is most efficacious and has the potential to reduce pathogens and spoilage bacteria to below detectable levels (Greer and Dilts, 1995). Research is necessary to establish a set of treatment conditions that may permit a practicable reduction in bacterial contamination with a measurable effect on safety and storage life without imposing any change in sensory properties. There have been efforts to alleviate the discolouration of meat associated with organic acid treatment. Thus, ascorbic and nicotinic acids reduced discolouration of pork carcasses following a 2% lactic acid spray (van Netten et al., 1995). Also, combinations of alginate and lactic acid have been found to limit pigment denaturation in restructured steaks (Baron et al., 1996). The combination of gluconic and lactic acid minimized colour defects in vacuum packaged beef (Zepeda et al., 1994b). The future may also offer the possibility of more innovative approaches including the immobilization of organic acids on meat packaging film.

7. Salts of organic acids and other derivatives

Salts of organic acids (primarily lactates) are approved for use as food ingredients and have been utilized traditionally to enhance the quality of cooked or cured meat products. Thus, they have been employed as emulsifiers, colour and flavour enhancers, humectants, and to control pH (Houtsma et al., 1993). Examples of products in which sodium lactate has been incorporated at concentrations ranging from 1 to 5% include cooked beef, liver paté, frankfurters, fresh pork sausage, beef patties and cooked poultry (Shelef, 1994). Some of the major general findings on the nature and degree of antimicrobial activity of lactates have been included in Table 10.

In cooked beef, sodium lactate was found to produce higher cooking yields, a darker redder colour and enhanced flavours at concentrations of 1 to 3% (Papadopoulos et al., 1991a,b). The limit of acceptability would appear to be 4% since panelists noted a mild throat irritation at acid levels of 4% (Papadopoulos et al., 1991a).

Investigations of the antibacterial properties of lactates are a more recent development. Researchers at the Agricultural University at Wageningen, Netherlands (de Wit and Rombouts, 1990; Houtsma et al., 1993) have compared the antibacterial activity of sodium lactate in laboratory culture media. Meat-borne spoilage bacteria (i.e., pseudomonads, *Brochothrix thermosphacta*) and human pathogens (i.e., *Yersinia*, *Salmonella*, *Listeria*) were inhibited and Gram positive bacteria were more sensitive to sodium lactate than Gram negative bacteria. These investigators concluded that the inhibitory effects of lactate were not solely due to a reduction in water activity (de Wit and Rombouts, 1990). Thus, accumulation of lactate anions or interference with proton gradients may be a factor contributing to the antibacterial activity of the molecule.

Shelef (1994) has compiled a definitive review of the antimicrobial properties of sodium, potassium and calcium lactates in numerous meat products. Reductions in total aerobic and anaerobic populations, coliforms, *C. botulinum* toxigenesis, psychrotrophs and *L. monocytogenes* were demonstrated. Following a study of precooked roast beef, Miller and Acuff (1994) concluded that 3% sodium lactate could be highly recommended from a food safety and sensory perspective. This concentration of lactate effectively limited the growth of both *S. typhimurium* and *E. coli* 0157:H7. This finding is contrary to de Wit and Rombouts (1990) who clearly demonstrated that a strain of *E. coli* was resistant to

Table 10
Lactates as decontaminants in meat and meat products

1. Nature of the antimicrobial effect
- Largely unknown!
- Obviously related to the lactate ion, as:
  Sodium lactate exerts a bigger effect than sodium chloride (Lamers, 1991)
  Sodium-, potassium- and calcium lactate produce similar effects (Chen and Shelef, 1992; Shelef and Yang, 1991)
  Calcium lactate has antimicrobial effects, whereas calcium carbonate, -chloride, -citrate and -phosphate have not (Shelef and Potluri, 1995)
- At almost neutral pH the portion undissociated acid is too small to account for the antimicrobial effect (Houtsma et al., 1994)
- The small reduction in a_w fails to explain the antimicrobial effect (Shelef, 1994)
- Calcium lactate addition to beef results in pH change from 6.3 to 5.8, the sodium- and potassium salts do not exert such an effect (Chen and Shelef, 1992)

2. Degree of antimicrobial activity
- More pronounced for calcium lactate than for the sodium- or potassium salts (Shelef and Potluri, 1995)
- Increases with decreasing Erh, possibly due to increased lactate concentration in the water phase (Chen and Shelef, 1992)
- Decreases with reduced fat content in sausages, possibly due to insolubility of fat (less fat → more water → dilution of lactate concentration) (Bradford et al., 1993)
- In meat greater than in culture broth (Shelef and Yang, 1991)
- Against *Listeria monocytogenes* increases with heat treatment and is highest at sterilization temperatures (heat-induced interaction of lactates and sausage components?) (Shelef and Potluri, 1995)
- Increases with decreasing temperatures (de Wit and Rombouts, 1990; Shelef and Potluri, 1995)
- Increases with decreasing pH (Houtsma et al., 1994)
- Against Gram negatives is less than against Gram positives (Houtsma et al., 1993)

sodium lactate. It was speculated than this resistance may be attributable to a comparatively larger proton motive force in this organism.

Salts of lactic acid are often used as an additional hurdle in combination with other antimicrobial factors such as sodium chloride or low moisture content (Chen and Shelef, 1992).

There have been some limited reports on the use of lactates in raw meat products in the absence of other additives. These studies have included fresh pork sausage (Lamkey et al., 1991), ground pork (Brewer et al., 1995), ground beef (Egbert et al., 1992) and pork loin (McKeith et al., 1994). In the comminuted products a 1 to 3 log reduction in bacterial counts was attributed to lactate treatment. Also, 3% sodium lactate was found to extend the lag phase of bacterial growth from 10 to 20 days and the shelf life of chub packs of sausage meat was increased by two weeks (Lamkey et al., 1991). The results of a recent study by Eckert et al. (1997) showed that lactate in combination with propionate could limit bacterial growth and enhance the sensory quality of aerobically stored ground beef patties.

Data from research on the treatment of intact raw meat portions with salts of organic acids are even more scarce. A study published by McKeith et al. (1994) revealed that a 3% sodium lactate dip produced a darker and redder colour in fresh pork chops but there were no differences on the extent of discolouration with storage time in comparison to controls. Although these investigators did not evaluate the bacteriological consequences of this treatment on fresh chops they did show that sodium lactate had no effect upon aerobic plate counts in cured chops.

There has been some conjecture that the success in storage life extension of ham, sausages and paté was due to the susceptibility of lactic acid bacteria to sodium lactate at low temperatures (de Wit and Rombouts, 1990). However, this contention was not supported in a recent study with beef treated with 2% sodium lactate and stored in controlled atmospheres containing carbon dioxide for up to 12 weeks at 1°C (Lynn McMullen, 1997, University of Alberta, personal communication). In comparison to untreated control beef, this treatment was without effect on the development of the lactic flora. Furthermore, sodium lactate treatment had no beneficial effect on colour, flavour or off-odour development.

Sorbates are salts of longer chain length acids that are permitted for use as food preservatives in most countries. Potassium sorbate has been shown to inhibit potent spoilers in the natural flora of beef including *Pseudomonas* spp., *Brochothrix thermosphacta*, *Lactobacillus* spp. and *Enterobacteriaceae* (Zamora and Zaritzky, 1987). These researchers also demonstrated that sorbate treatment produced higher Hunter a values during 42 days of meat storage.

In an earlier study, Greer (1982) determined the effect of a potassium sorbate dip upon the growth of bacteria and the colour case life of retail beef steaks. As shown in Table 11, sorbate produced a dramatic increase in the lag phase of bacterial growth without affecting the rate of growth. Consequently, retail case life was significantly increased from two to four days. The increase in retail case life was due to an improved acceptability of lean colour. Lactates would also appear to extend the lag phase of bacterial growth in ground pork (Brewer et al., 1995).

It would be of value to consider other complexes of organic acids that have been evaluated as preservatives in meats. Food grade esters of fatty acids (lauric, palmitic, steoric, oleic) did not inhibit psychrotrophs, mesophiles or the growth of *E. coli* 0157:H7 in ground beef (Hathcox and Beuchat, 1996). These authors further demonstrated that although sucrose laurate did not have lethal effect on *E. coli* 0157:H7 inoculated on to beef slices, this treatment appeared to remove a significant number of bacteria from the surface.

There has been some interesting research on the antimicrobial properties of amino acid and fatty acid complexes (fatty-*N*-acylamino acids) originally synthesized by Paquet (Paquet, 1980; Paquet and Rayman, 1987). Myristoyl (C_{14}) derivatives were most active and inhibition was demonstrable against Gram-positive foodborne pathogens but not Gram-negative organisms (McKellar et al., 1992). The results of (unpublished) research by Greer and Paquet, have demonstrated that the sodium salt of a myristoyl–methionine complex can inhibit the aerobic growth of *B. thermosphacta* inoculated on to fresh pork (Table 12). The data show an initial bactericidal effect followed by bacteriostasis for up to nine days of aerobic storage. It would be expected that fatty-*N*-acylamino acids would not pose a risk to human health if consumed in foods, but regulatory approval has yet to be sought.

In summary, in contrast to the numerous reports of research on organic acids there are comparatively few studies on the antibacterial efficacy of their salts, and the research that is available has emerged from laboratory investigations rather than commercial trials. Salts of lactic and sorbic acid would appear to act primarily as bacteriostatic agents while organic acids demonstrate both bactericidal and bacteriostatic properties. Although somewhat removed from the focus of this review, there have been some comparatively recent investigations of the antibacterial properties of derivatives of fatty acids (sucrose esters, fatty acylamino acids). These latter compounds may play a role in improving the bacterial condition of meat in the future but considerably more research is necessary.

Available data indicate that lactates are not very active antimicrobials in raw meats stored in air or vacuum and there is no known research on their application to red meat carcasses. They may play a more significant role as preservatives in cooked or cured products in combination with other hurdles.

To comply with the objectives of this review it is

Table 11
Effect of potassium sorbate on the growth of psychrotrophic bacteria and beef case life

Treatment	Lag phase (d)	Growth rate (generations/h)	Case life (d)
Control	0.4	0.23	2.1
10% Potassium sorbate	4.0	0.24	4.0

Greer (1982).
Steaks were immersed in a 10% solution (w/v) of potassium sorbate for 1 min followed by simulated retail display for 10 d at 3°C.
Case life was estimated on the basis of lean acceptability evaluated using a five-member sensory panel.

Table 12
Effect of myristoyl-methionine on the aerobic growth of *Brochothrix thermosphacta* on pork

Storage	Log bacteria/cm^2	
time (d)	Control	2% Myristoyl-methionine
0	3.56	2.00
2	3.97	2.00
4	5.00	2.12
7	6.64	3.05
9	7.07	3.10

G.G. Greer and A. Pacquet (1997, unpublished).
Inoculated pork tissue discs were immersed in a 2% solution of the sodium salt of myristoyl-methionine for 15 s followed by aerobic storage at 4°C.

necessary to consider the practical value of salts of organic acids within the context of a HACCP-based system. There is no evidence to date which would support their use in treatment of red meat carcasses to improve meat safety or as an adjunct to HACCP in meeting specified performance standards for pathogen reduction. It is conceivable that salts of organic acids could play a role as decontaminants of subprimal cuts prior to packaging. This assumption is based upon their beneficial attributes in stabilizing meat colour. However, since their antibacterial potential in raw products has yet to be substantiated they may have to be applied in combination with a more efficacious antimicrobial.

8. Future role of organic acids in a HACCP-based system

Major disadvantages of the use of decontaminants identified by the EUs Advisory Scientific Veterinary Committee were termed as: ''... removing incentives for farmers to continue developing good sanitation in their flocks'' and ''... neglecting the use of Good Manufacturing Practice (GMP) in the whole production chain''. Although they felt unable to generally recommend introduction of decontamination techniques in food processing, the group argued that – for a transitional period and solely as a supplementary measure and not in any way compromising the use of Good Hygiene Practice – the use of decontaminants might be considered. During a more recent meeting of the EUs Permanent Veterinary Committee (February, 1997) a majority of member-states regarded the currently available documentation as not yet convincing enough to allow considering introduction of decontamination in the EU, albeit that a limited number of national representatives were either positively in favour, or regarded the use of decontaminants under strict conditions as a conceivable future option.

The Food Safety Inspection Service (FSIS) of the US Department of Agriculture (USDA) developed a comprehensive treatise of requirements designed to reduce pathogenic microorganisms on meat. These rules and regulations were advanced in a document entitled ''Pathogen Reduction; Hazard Analysis Critical Control Point (HACCP) System'' proposed rule now referred to as the ''Pathogen Reduction/HACCP Proposal'' in the Federal Register on February 23, 1995 (USDA, 1995).

This ''Mega Reg'' included a proposal for antimicrobial treatments at slaughter. The treatment was to be applied to the carcass at a point in the dressing process prior to entry into the chiller. Such treatments included chlorine solutions, hot water or any antimicrobial compound approved by the US Food and Drug Administration (FDA) (i.e., organic acids, trisodium phosphate). Inspectors would have had the authority to retain carcasses not exposed to at least one antimicrobial treatment. The underlying philosophy was that even with best current practices some contamination of carcasses with human pathogens is implicit and intervention is necessary to reduce the safety hazard.

After numerous information meetings, technical conferences, public hearings and the receipt of 6800 comments, the proposed rule was modified in accordance with some of the views expressed by the commentators. The modified ''final rule'' with a request for comment was published in the Federal Register, July 25, 1996 (USDA, 1996).

Commentators rejected the mandated requirement for an antimicrobial treatment. The reason for this response was two-fold. The HACCP philosophy contends that each establishment management would be responsible for designing a system of process control appropriate for and specific to the establishment. Mandating an antimicrobial treatment is not in the spirit of this philosophy. And, because establishments would be required to meet pathogen reduction performance standards (i.e., *Salmonella*, *E. coli*) a specification of mandatory antimicrobial treatments would not be necessary. Consequently, the FSIS reconsidered the proposed final rule and has decided not to mandate antimicrobial treatments in slaughter facilities.

The final rule does clearly state that federally inspected establishments must implement HACCP systems for the slaughter of all species over the next three years. Canadian regulators are proceeding on a parallel course and, with the implications associated with free trade, harmonization of regulations is imminent.

It is recognized that antimicrobial treatments will not be a substitute for sanitary dressing procedures and shall not displace sanitation standard operating procedures (sanitation SOPs). In Canada organic acid (lactic/acetic) carcass rinses were approved as a ''processing aid'' with approval of the establishments quality control program. It is the hope of the FSIS that in order to comply with performance standards for pathogen reduction, processing facilities will voluntarily select an antimicrobial treatment tailored to their specific needs. With this flexibility, it is likely that organic acids carcass decontamination will be included as an adjunct to HACCP in American abattoirs and their use may increase with the pressure of imposed performance standards (J. Sofos, 1997, Colorado State, personal communication).

The requirement to meet pathogen reduction performance standards has prompted a number of studies over the past three years where antimicrobial intervention strategies have been compared. The data in Table 13 summarizes some of these published results. It is evident that water and steam sanitizing treatments often produce reductions in pathogens of a magnitude similar to that of organic acids. Thus, the industry must carefully evaluate the benefits, risks, costs, and operational consequences when selecting an appropriate decontamination procedure.

It is of importance to note that the currently proposed regulations were primarily designed to reduce bacterial contamination on carcasses that had accumulated during the dressing process. There is a body of published data showing that the marginal reduction in bacterial numbers offered by organic acid treatment of carcasses is without impact upon the bacterial quality or storage life of subprimal and retail cuts derived from treated carcasses (Greer and Jones, 1991; Kenney et al., 1995; Siragusa, 1995). Also, pathogenic enteric organisms such as *Salmonella* and *E. coli* are among the most resistant to organic acids (Greer and Dilts, 1992; Brackett et al., 1994). These observations are ironic in that these pathogens are targeted in the proposed mandatory performance standards.

It is evident that the limited reduction in carcass surface contamination attributed to organic acid sprays is negated by recontamination during the subsequent carcass breaking and further processing steps. With the current North American focus on boxed meat production for domestic distribution and export markets the bacterial condition and safety of vacuum packaged subprimals becomes the critical consideration. Thus, organic acids may play an important future role as a terminal processing treatment immediately prior to vacuum packaging. To this end, practicable treatment conditions must be established that will facilitate an improvement to safety and storage stability without sacrificing the acceptable sensory properties. A 2% lactic/acetic acid spray treatment has recently been described that will reduce bacterial populations on beef strip loins during storage at -1°C for 112 days without any adverse affects upon the physical properties of the

Table 13
Comparison of intervention strategies for meat decontamination

Meat	Method	Log reduction	Ref.
Pork carcass (natural contamination)	85°C water	2 (coliforms/*E. coli*)	Gill et al., 1997
Inoculated beef short plates	Steam/vacuum	4 (coliforms/*E. coli*)	Dorsa et al., 1996a
Inoculated *Cutaneous trunci*	70°C water	2.7 (*E. coli* 0157:H7)	Cutter et al., 1997
	70°C acetic	5.0	
Inoculated beef brisket	74°C water	3 (total counts)	Gorman et al., 1997
Inoculated beef brisket	Trim	3.3 (*E. coli* 0157:H7)	Hardin et al., 1995
	35°C water	3.0	
	Water/55°C lactic	4.2	
	Water/55°C acetic	3.0	

meat (Goddard et al., 1996). It remains to be determined whether this type of treatment will find its way into commercial practice.

9. Conclusions

The USDAs ''Pathogen Reduction/HACCP Proposal'' (USDA, 1996) includes recommendations for voluntary antimicrobial interventions such as organic acids, trisodium phosphate, hot water or steam. With HACCP implementation imminent, research in this area is considerable, but most efficacy data result from laboratory studies and extrapolation to commercial practice is not warranted. Moreover, single point intervention strategies such as organic acid decontamination are largely focused on decontamination of the carcass surface. Many investigators have shown that the limited reduction in bacteria on the carcass cannot be related to the safety of the resultant meat and recontamination/growth during further processing and storage is inevitable.

A viable alternative would be the decontamination of subprimal cuts prior to packaging. Thus, organic acids have an advantage over many other decontamination procedures in that residual antimicrobial effects have been observed both during storage in air and after several weeks in vacuum.

An impediment to the application of organic acids to cut meat surface is the undesirable deterioration of appearance. Commercial trials are necessary to develop and evaluate organic acid systems tailored to the commercial environment that will improve meat safety without sacrificing the desirable sensory properties. Only when this information becomes available will it be possible to convince regulatory agencies and meat processors to redirect some of their decontamination efforts to post-carcass processing and storage. The result could be multi-point interventions at strategic points from the live animal through to the retail product.

There are basic philosophical differences in arguments advanced by the EU and the USDA with respect to decontamination. Regulatory authorities in the EU contend that strictly hygienic processing is sufficient to assure product safety. Thus, decontamination strategies are perceived as a means of concealing poor hygiene.

On the other hand, the USDA acknowledges that even with best, current, hygienic practices some contamination of the carcass is inevitable. Interventions are therefore perceived as an adjunct to HACCP in meeting pathogen reduction performance standards. Unfortunately, the arguments cannot be resolved with subjective, organoleptic criteria for assessing dressing hygiene. With the development of practicable, objective measures to assess the hygienic characteristics of carcass dressing processes, including standardized techniques, resolution is possible. Such a method using total *E. coli* counts has recently been proposed (Gill et al., 1996).

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