THE EFFECTIVENESS OF CARCASS DECONTAMINATION SYSTEMS FOR CONTROLLING THE PRESENCE OF PATHOGENS ON THE SURFACES OF MEAT ANIMAL CARCASSES[1]

GREGORY R. SIRAGUSA[2,3]

United States Meat Animal Research Center
United States Department of Agriculture
Agricultural Research Service
P.O. Box 166
Clay Center, NE 68933

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ABSTRACT

The effectiveness of decontamination systems for controlling the presence of pathogens and spoilage organisms on carcasses is discussed. Research using organic acids and water (hot or cold) demonstrates the general effectiveness of such treatments in lowering the aerobic plate counts (APC) on carcasses by 1–3 log_{10} cfu per unit area. Chlorine has been found to be relatively ineffective for use in animal carcass spray washers. An example of direct application of the bacteriocin nisin to inoculated tissue in a spray washer is discussed. Reductions attributable to nisin were 2–2.5 log_{10} cfu per unit area higher than those reported for various organic acids or water. Areas for further research are highlighted along with the potential use of newer technologies to elucidate attachment and detachment mechanisms of bacteria to meat animal carcasses.

INTRODUCTION

The process of converting live meat animals into carcasses for further processing has been modernized, streamlined, quickened, and made more

[1] Mention of a trade name, proprietary product or specific equipment is necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

[2] To whom correspondence should be addressed. Corresponding author's telephone number: (402) 762-4227; FAX (402) 762-4149.

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efficient. Despite this, all carcasses will have a microbial flora associated with them. It is not possible to reduce the level of microbial contamination on a carcass to zero using a washing system.

Carcass decontamination refers largely to the use of carcass spray washing systems which are employed to reduce and/or kill bacteria on carcasses. Most of the available research has been conducted using tissue models of the larger process of in-plant carcass washing systems. Spray washers must be judged as a single step in the whole process of producing hygienic carcasses and not as a single step towards pathogen reduction. They can only be considered a single point in a HACCP program.

The body of work presented in this review is largely from laboratory scale experiments on small pieces or cuts of meat or pilot scale carcass washers. Such research yields data that is highly variable from study to study. This variation is expected, since experiments testing carcass spray washing efficacy have a large number of variables (inoculum species, inoculum level, inoculum contact time, temperature, age of samples, enumeration assays, sampling methods, contact time, spray pressure, antimicrobial agents, concentration, etc.) which are rarely reproducible from laboratory to laboratory.

Carcass decontamination systems in the United States of America usually employ potable tap water in their sprayers. On a limited basis, some processors use low concentrations of acetic acid. This paper will review the use of organic acids, chlorine, water and recently bacteriocins, in decontamination systems designed to reduce the levels of bacterial pathogens on carcasses. The intention is to review the literature in terms of effectiveness of the practice of spray washing. For more comprehensive reviews of decontamination, references are available (Dickson and Anderson 1992).

ORGANIC ACID DECONTAMINATION

Short chain organic acids have been targeted as the most logical agents to spray on carcasses as antimicrobial agents. Lactic, acetic, citric, formic and propionic acids have all been reported in the literature for this purpose. Lactic and acetic acids are inexpensive, have GRAS status, are environmentally friendly, and are naturally occurring. Recently, longer chain fatty acid derivatives, such as monolaurin, have received attention as meat antimicrobials. Table 1 gives several examples of the reported results from using short chain organic acids as antimicrobial agents.

These data are summarized to illustrate that, although each experiment was uniquely different in design (application, inoculum, microbial detection, species, sample type, etc.) the results are remarkably similar. As a general statement, the use of organic acids reduced bacterial counts by 1–2 $\log_{10}$ cfu/area of tissue surface, regardless of the acid type. The antimicrobial effect of short chain fatty acids is largely due to lowering of the pH where the undissociated form of the acid is maintained (Gill and Newton 1982; Cutter and Siragusa 1994a). Acid concentration appears to be an important factor in the magnitude of the immediate pH drop and antimicrobial effect. However, at high acid concentrations the effects of these compounds on product quality (color, flavor) become important considerations.

The use of acid mixtures has been studied. Hypothetically, citric or ascorbic acids are thought to exert a chelating effect that enhances the pH lowering effect of either acetic or lactic acids. However this concept, while perhaps mechanistically sound, does not seem to provide a substantially larger reduction of bacterial counts on carcasses.

The last criterion for judging the effectiveness of acid spray washing is the shelf-life of stored meat products prepared from spray washed cuts. At least three studies have demonstrated no difference in the aerobic plate counts between products prepared from acid spray washed cuts and controls after refrigerated storage (Acuff *et al.* 1987; Dickson and Anderson 1991; Prasai *et al.* 1991).

CHLORINE DECONTAMINATION

The use of chlorinated water to decontaminate carcasses has received much attention (Table 2). Overall, most researchers conclude that chlorine has little or no effect, unless it is sprayed frequently over a prolonged period of time. These results are not surprising considering the infinitely larger organic load contributed by a carcass or tissue section, compared to the small amounts of free available chlorine in the spray solutions. The applied chlorine very rapidly becomes bound by the organic load and is no longer antimicrobial.

With the current climate of concern over the potential of chloramine formation from chlorine, it is probable that chlorine usage will decrease, if not be eliminated altogether. It may be replaced with compounds such as chlorine dioxide for the purposes of carcass decontamination.

WATER DECONTAMINATION AND THE ATTACHMENT PROCESS

Of all the treatments for decontaminating carcasses, rinsing the carcass with water is perhaps the single most effective means to remove at least one $\log_{10}$ APC unit from the carcass surface. In the case of hot water spray washing, the reduction is significantly higher and can be as much as >3 $\log_{10}$ APC or specific organism reduction. The data presented in Table 3 illustrates this point. The trend in this data does not differ greatly from that observed using organic acids, with the exception of hot water spray washing.

TABLE 1.
EXAMPLES OF THE USE OF SHORT CHAIN ORGANIC ACIDS TO DECONTAMINATE MEAT ANIMAL CARCASSES OR TISSUES

Acid Type	Species	Concentration	Effect	Reference
lactic + acetic mix	lamb	6 - 24% (v/v)	≤ 1 $\log_{10}$ APC reduction	Ockerman *et al.* 1974
acetic + proprionic mix	swine	60:40 mix	2 $\log_{10}$ APC reduction	Reynolds and Carpenter 1974
lactic	calves	0.75 - 2.5% (v/v)	≅ 1 $\log_{10}$ APC reduction	Woolthuis and Smulders 1985
acetic, lactic	beef	1%	no significant reduction from controls after vacuum packaged storage	Acuff *et. al.* 1987
lactic, acetic, ascorbic citric mixture	beef	1% lactic, 2% acetic, 0.25% citric, 0.1% ascorbic	no significant reduction from controls after vacuum packaged storage	Acuff *et. al.* 1987
lactic	veal tongues	2% (v/v)	≅ 3 $\log_{10}$ APC reduction	Visser *et al.* 1988
lactic	beef	3% (v/v)	≅ 1.8 $\log_{10}$ APC reduction @ 70°C ≅ 1.1 $\log_{10}$ *E. coli* reduction @ 70°C ≅ 1.2 $\log_{10}$ APC reduction @ 25°C ≅ 0.4 $\log_{10}$ *E. coli* reduction @ 25°C	Anderson and Marshall 1990
acetic	beef	2% (v/v) 55°C	≥2 $\log_{10}$ reduction of *Salmonella california*	Dickson and Anderson 1991
lactic	swine	1% (v/v), 55°C	≅ 1 $\log_{10}$ APC reduction	Prasai *et al.* 1991
lactic	beef	1% (v/v), 55°C	≅ 1 $\log_{10}$ APC reduction	Prasai *et al.* 1991
lactic	beef	1% (v/v), 55°C	≅ 1.0 $\log_{10}$ APC reduction immediately, but no significant difference after 3 d b/w treated and controls	Prasai *et al.* 1991
acetic	beef	1.5 - 3% (v/v)	< 1.0 $\log_{10}$ APC, enterobacteriaceae, and *Salmonella typhimurium* reduction @ 20°C	Anderson *et al.* 1992
lactic	beef	1.5 - 3% (v/v)	< 1.5 $\log_{10}$ APC, enterobacteriaceae, and *Salmonella typhimurium* reduction @ 20°C	Anderson *et al.* 1992

Continued

TABLE 1. (CONTINUED)

Acid Type	Species	Concentration	Effect	Reference
acetic + lactic	beef	2% acetic +1% lactic	< 1.0 log_{10} APC, enterobacteriaceae, and *Salmonella typhimurium* reduction @ 20 C	Anderson, Marshall, and Dickson, 1992
lactic + acetic	beef	2% lactic + 1% acetic	< 1.0 log_{10} enterobacteriaceae, and *Salmonella typhimurium* reduction @ 20°C ≅ 1.1 log_{10} APC reduction	Anderson *et al.* 1992
acetic	beef	2% (v/v) in alginate gel	≅ 1.5 log_{10} *Listeria monocytogenes* reduction	Siragusa and Dickson 1992
lactic	beef	1.7% (v/v) in alginate gel	≅ 1.3 log_{10} *Listeria monocytogenes* reduction	Siragusa and Dickson 1992
lactic and acetic	beef	1, 3, 5 % (v/v)	≤ 1.75 log_{10} reduction of *E. coli* O157:H7	Cutter and Siragusa 1994a
lactic and acetic	beef	1, 3, 5 % (v/v)	≅ 3.5 log_{10} reduction of *Pseudomonas fluorescens*	Cutter and Siragusa 1994a

The fact that water spraying can often effect a comparable reduction in APC, as spraying with organic acids, is evidence that the physical removal of bacteria from the layer of surface water surrounding the carcass is the important step in effective spray washing. The process of bacterial attachment is complex even if the underlying attachment surface is inert and homogenous (e.g., stainless steel). In the case of an animal carcass, the number of variables increases greatly and the attachment process becomes orders of magnitude more complicated. The attachment process is thought to be in two stages (Marshall 1977), the first stage being reversible and the second stage more permanent or irreversible. The first stage is largely characterized as a physical phenomenon between the particle (bacterium) and the surface (carcass). The second stage is thought to be accompanied by the synthesis or action of either a general attachment substance (e.g., extracellular bacterial polysaccharide) or a specific attachment to substrate entities (e.g., lectins).

General antimicrobial agents, such as organic acids, are apparently effective on those organisms that are contacted by the acid for a long enough period of time to effect a lethal or inhibitory response. However, for organisms that are not in contact with the agent for a sufficient period of time, or have become entrapped or protected in the carcass surface, the application of an antimicrobial has no real effect. In the literature, the concentrations of organic acids applied are often well below the levels needed to effect any adverse physiological response, much less lethality, for species such as *E. coli* (Cutter and Siragusa 1994a). Therefore, the combination of a means to physically remove or loosen attached bacteria on carcasses followed by an antimicrobial spray or hot water,

TABLE 2.
EXAMPLES OF THE USE OF CHLORINE TO DECONTAMINATE MEAT ANIMAL CARCASSES OR TISSUES

Agent	Species	Concentration	Effect	Reference
chlorine	beef	200 mg/l	≤ 2 $\log_{10}$ APC immediate reduction ≥ 2 $\log_{10}$ APC reduction post 24 h	Kotula *et al.* 1974
chlorine	beef	100 - 400 mg/l	1.5 - 1.8 $\log_{10}$ APC reduction post 24h	Emswiler *et al.* 1974
chlorine	beef	electrically generated	no significant APC reductions between treated and untreated	Marshall *et al.* 1977
chlorine	beef	200 mg/l	no differences in APC, coliforms, or staphylococci between treated and untreated samples	Stevenson *et al.* 1978
chlorine	beef	200 mg/l	initial reduction in APC but no differences post 8 d	Titus *et al.* 1978
chlorine	beef	200 mg/l	no differences in APC or total lactics between treated and untreated	Johnson *et al.* 1979
chlorine	lamb	450 mg/l @ 80°C	immediate APC reduction but no differences post 7d	Kelly *et al.* 1981
chlorine	pork	200 mg/l	1.5 $\log_{10}$ psychrotrophic count reduction	Skelly *et al.* 1985
chlorine	beef	50 - 800 mg/l	no significant *E. coli* reductions between treated and untreated	Cutter and Siragusa 1995

addresses the two steps (i.e., detachment and inactivation) necessary for a carcass decontamination system to be effective.

Most of the model systems used to evaluate the effectiveness of carcass washing systems use a very large level of inoculum or rely on endogenous contamination to demonstrate spray washing efficacy. Both of these extremes can lead to erroneous conclusions. Researchers could benefit by using a more moderate or realistic level of organisms inoculated on tissue ($\log_{10}$ 2–3 cfu/cm^2). As an example, Barkate *et al.* (1993) sprayed hot water on uninoculated carcasses that had bacterial levels of $\log_{10}$ 2.3–2.4 APC cfu/cm^2 before treatment. Following treatment with hot water (95°C at source, 82°C on carcass surface) the levels decreased to a mean of $\log_{10}$ 1.3 APC cfu/cm^2. The levels detected following treatment are at the lower limits of detection for the standard plate count. These results are probably a more accurate reflection of commercial carcass washer efficacy than laboratory model generated data with artificially inoculated carcass tissues.

TABLE 3.
EXAMPLES OF THE USE OF WATER RINSING TO DECONTAMINATE MEAT ANIMAL CARCASSES OR TISSUES

Agent	Species	Conditions	Effect	Reference
water	beef	85 - 499 kPa pressure	significant surface reduction b/w pressures	Kotula *et al.* 1974
water	beef	80°C	2.64 $\log_{10}$ *E. coli* reduction 2.21 $\log_{10}$ *Salmonella* reduction	Smith and Graham 1978
water	mutton	80°C	3.32 $\log_{10}$ *E. coli* reduction 3.33 $\log_{10}$ *Salmonella* reduction	Smith and Graham 1978
water	beef	commercial carcass washing unit	1.07 $\log_{10}$ APC reduction	Anderson *et al.* 1987
water	beef	hand washed with hose	0.99 $\log_{10}$ APC reduction	Anderson *et al.* 1987
water	beef	83.5°C at carcass surface	2.23 $\log_{10}$ APC reduction, 10 sec exposure; 2.98 $\log_{10}$ APC reduction, 20 sec exposure	Davey and Smith 1989
water	beef	550 kPa (80 psi)	1 - 1.9 $\log_{10}$ reduction of *E. coli* O157:H7	Cutter and Siragusa 1994b
water	beef	95°C spray gum application, 82°C at carcass surface	1.05 $\log_{10}$ APC reduction on uninoculated beef sides	Barkate *et al.* 1993

BACTERIOCINS AS CARCASS DECONTAMINATING AGENTS

To date, the use of bacteriocins as carcass decontaminating agents has been reported only once (Cutter and Siragusa 1994b). Nisin was applied to separate beef carcass surface tissues, inoculated with approximately $\log_{10}$ 4 cfu/cm^2 of *Listeria innocua, Carnobacterium divergens* or *Brochothrix thermosphacta*. Reductions of 3.3, 3.0 and 3.6 $\log_{10}$ cfu/cm^2 respectively, were effected after storage of carcasses for 24 h at 5°C. The control tissues sprayed with water showed a reduction of < 1 $\log_{10}$ for each species. The magnitude of the nisin reduction is largely dependent on the susceptibility of the individual strain and species of target organism. A major step would be to demonstrate the effectiveness of bacteriocins against Gram negative pathogens. A measure of the effect of bacteriocin purity in eliminating pathogens would also be valuable. This will require new or different agents with wider bactericidal range or the use of agents (i.e., EDTA) that enhance the current efficacy of bacteriocins. The application of bacteriocinogenic cultures directly to the carcass is another possibility.

CONCLUSIONS AND FUTURE QUESTIONS TO BE ADDRESSED

For the removal of gross physical contaminants and the improvement of carcass appearance, spray washing has a definite role. The microbiological effects of spray washing are limited, irrespective of the substance used. Reductions of 1–2 $\log_{10}$ cfu/cm^2 can be achieved with these treatments. The reduction in bacterial counts is usually immediate in the case of organic acid treatments, and efficacy should be determined on a longer term basis. When considering this factor, the limited data suggests that from a shelf-life perspective, spray washing with organic acids has no lasting effects. However, in relation to pathogen removal, at least one report demonstrates that the levels of pathogens on acid treated tissue are lower than on untreated tissue. The production of safe carcasses at an economical treatment cost will also be a priority.

An understanding of the interaction of bacteria with the surface water layer of carcasses and the mechanisms of bacterial attachment will be pivotal if carcass washing treatments are to be made more effective in pathogen removal or inactivation. Since the levels of pathogens on carcasses are generally low, spray washing might have a positive public health effect (Dickson and Siragusa 1994).

Bacteriocins show great potential for use in carcass decontamination, especially for specific pathogens, although their use will require approval as a food additive. Ultimately, cost may be the deciding factor in their usage as carcass decontaminating agents.

Altering the final microfloral population could have potential negative effects on what are considered to be beneficial bacteria, such as lactics, or spoilage pseudomonads that are potential organoleptic signals of spoilage. Where all viable bacteria (benign, beneficial or pathogenic) on a carcass surface are eliminated, very real safety concerns arise because the potential for pathogen dominance becomes possible. If the goal of carcass decontamination is to lower the frequency of pathogen transmission, this is achievable when these systems are used as a part of the whole process of pathogen reduction.

REFERENCES

ACUFF, G.R., VANDERZANT, C., SAVELL, J.W., JONES, D.K., GRIFFIN, D.B. and EHLERS, J.G. 1987. Effect of acid decontamination of beef subprimal cuts on the microbiological and sensory characteristics of steaks. Meat Sci. *19*, 217–226.

ANDERSON, M.E., HUFF, H.E., NAUMANN, H.D., MARSHALL, R.T., DAMARE, J.M., PRATT, M. and JOHNSTON, R. 1987. Evaluation of an automated beef carcass washing and sanitizing system under production conditions. J. Food Prot. *50*, 562-566.

ANDERSON, M.E. and MARSHALL, R.T. 1990. Reducing microbial populations on beef tissues: concentration and temperature of lactic acid. J. Food Safety *10*, 181-190.

ANDERSON, M.E., MARSHALL, R.T. and DICKSON, J.S. 1992. Efficacies of acetic, lactic, and two mixed acids in reducing numbers of bacteria on surfaces of lean meat. J. Food Safety *12*, 139-147.

BARKATE, M.L., ACUFF, G.R., LUCIA, L.M. and HALE, D.S. 1993. Hot water decontamination of beef carcasses for reduction of initial bacterial numbers. Meat Sci. *35*, 397-401.

CROUSE, J.D., ANDERSON, M.E. and NAUMANN, H.D. 1988. Microbial decontamination and weight of carcass beef as effected by automated washing pressure and length and time of spray. J. Food Prot. *51*, 471-474.

CUTTER, C.N. and SIRAGUSA, G.R. 1994a. Efficacy of organic acids against *Escherichia coli* O157:H7 attached to beef carcass tissue using a pilot scale model carcass washer. J. Food Prot. *57*, 97-103.

CUTTER, C.N. and SIRAGUSA, G.R. 1994b. Decontamination of beef carcass tissue with nisin using a pilot scale model carcass washer. Food Microbiol. *11*, 481-489.

CUTTER, C.N. and SIRAGUSA, G.R. 1995. Application of chlorine to reduce populations *Escherichia coli* on beef. J. Food Safety *15* (1), 67-75.

DAVEY, K.R. and SMITH, M.G. 1989. A laboratory evaluation of a novel hot water cabinet for the decontamination of sides of beef. Int. J. Food Sci. Technol. *24*, 305-316.

DICKSON, J.S. and ANDERSON, M.E. 1991. Control of *Salmonella* on beef tissue surfaces in a model system by pre- and post-evisceration washing and sanitizing, with and without spray chilling. J. Food Prot. *54*, 514-518.

DICKSON, J.S. and ANDERSON, M.E. 1992. Microbiological decontamination of food animal carcasses by washing and sanitizing systems: A review. J. Food Prot. *55*, 133-140.

DICKSON, J.S. and SIRAGUSA, G.R. 1994. Survival of *Salmonella typhimurium, Escherichia coli* O157:H7, and *Listeria monocytogenes* during storage on beef sanitized with organic acids. J. Food Safety *14*, 313-327.

EMSWILER, B.S., KOTULA, A.W. and ROUGH, D.K. 1976. Bactericidal effectiveness of three chlorine sources used in beef carcass washing. J. Anim. Sci. *42*, 1445-1450.

GILL, C.O. and NEWTON, K.G. 1982. Effect of lactic acid concentration on growth on meat of gram-negative psychrotrophs from a meat-works. Appl. Environ. Microbiol. *43*, 284-288.

JOHNSON, M.G., TITUS, T.C., McCASKILL, L.H. and ACTON, J.C. 1979. Bacterial counts on surfaces of carcasses and in ground beef from carcasses sprayed or not sprayed with hypochlorous acid. J. Food Sci. *44*, 169-173.

KELLY, C.A., DEMPSTER, J.F. and McLOUGHLIN, A.J. 1981. The effect of temperature, pressure, and chlorine concentration of spray washing water on numbers of bacteria on lamb carcasses. J. Appl. Bact. *51*, 415–424.

KOTULA, A.W., LUSBY, W.R., CROUSE, J.D. and de VRIES, B. 1974. Beef carcass washing to reduce bacterial contamination. J. Anim. Sci. *39*, 674–679.

MARSHALL, R.T., ANDERSON, M.E., NAUMANN, H.D. and STRINGER, W.C. 1977. Experiments in sanitizing beef with sodium hypochlorite. J. Food Prot. *40*, 246–249.

OCKERMAN, H.W., BORTON, R.J., CAHILL, V.R., PARRETT, N.A. and HOFFMAN, H.D. 1974. Use of acetic and lactic acid to control the quantity of microorganisms on lamb carcasses. J. Milk Food Technol. *37*, 203–204.

PRASAI, R.K., ACUFF, G.R., LUCIA, L.M., HALE, D.S., SAVELL, J.W. and MORGAN, J.B. 1991. Microbiological effects of acid decontamination of beef carcasses at various locations in processing. J. Food Prot. *54*, 868–872.

REYNOLDS, A.E. and CARPENTER, J.A. 1974. Bactericidal properties of acetic acids on pork carcasses. J. Anim. Sci. *38*, 515–519.

SIRAGUSA, G.R. and DICKSON, J.S. 1992. Inhibition of *Listeria monocytogenes* on beef tissue by application of organic acids immobilized in a calcium alginate gel. J. Food Sci. *57*, 293–296.

SKELLY, G.C., FANDINO, G.E., HAIGLER, J.H. and SHERARD, R.C. 1985. Bacteriology and weight loss of pork carcasses treated with a sodium hypochlorite solution. J. Food Prot. *48*, 578–581.

SMITH, G.C., VARNADORE, W.L., CARPENTER, Z.L. and CALHOUN, M.C. 1976. Post-mortem treatment effects on lamb shrinkage, bacterial counts, and palatability. J. Anim. Sci. *42*, 1167–1174.

SMITH, M.G. and GRAHAM, A. 1978. Destruction of *Escherichia coli* and salmonellae on mutton carcasses by treatment with hot water. Meat Sci. *2*, 119–128.

STEVENSON, K.E., MERKEL, R.A. and LEE, H.C. 1978. Effects of chilling rate, carcass fatness and chlorine spray on microbiological quality and case life of beef. J. Food Sci. *43*, 849–852.

TITUS, T.C., ACTON, J.C., McCASKILL, L. and JOHNSON, M.G. 1978. Microbial persistence on inoculated beef plates sprayed with hypochlorite solutions. J. Food Prot. *41*, 606–612.

VISSER, I.J.R., KOLMEES, P.A. and BIJKER, P.G.H. 1988. Microbiological conditions and keeping quality of veal tongues as affected by lactic acid decontamination and vacuum packaging. J. Food Prot. *51*, 208–213.

WOOLTHUIS, C.H.J. and SMULDERS, F.J.M. 1985. Microbial decontamination of calf carcasses by lactic acid sprays. J. Food Prot. *48*, 832–837.