New Intervention Technologies

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Introduction

In 1996, the USDA-Food Safety Inspection Service (FSIS) published the final rule of the Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems. As part of the regulation, the FSIS did not mandate the use of antimicrobial or intervention treatments for reducing bacterial contamination on muscle food surfaces. Rather, FSIS ". . .proposed that all slaughter establishments apply at least one antimicrobial treatment or other approved intervention to livestock and poultry carcasses prior to chilling or cooling operation" and ". . . slaughter establishments will find that these treatments can play a useful role in reducing pathogens and improving the safety of meat and poultry products." Along with a list of suggested antimicrobial interventions (Table 1), FSIS ". . . encourages the development of efficacious, practical, and manageable technologies and procedures by establishments" (Federal Register, volume 61, p. 38854). In addition, FSIS "confirmed its long-standing commitment to foster innovative technologies and procedures that more effectively protect meat and poultry products from microbiological and other hazards" (Federal Register, volume 61, p. 38854). As part of the intervention approval process, FSIS has published guidelines for submission of written proposals and protocols (Table 2).

Organic acid rinses, steam vacuuming, steam pasteurization, and hot water washes have been documented as effective intervention measures and are currently used by the meat industry for removal of visible and bacterial contamination from poultry and red meat animal carcasses (for review of these subjects, see Dickson and Anderson, 1992; Dorsa, 1997; Siragusa, 1995). Despite the effectiveness and widespread use of these interventions, researchers and industry are continuing to investigate new methodologies for improving the microbiological safety and quality of carcasses, subprimals, and retail products.

Not all post-harvest technologies presented in this paper are new or novel. Rather, the renewed interest in pathogen reduction mechanisms for muscle foods warrants the discussion of methods that have the potential to be applied and implemented in slaughter or fabrication establishments. These technologies include thermal (desiccation with heat and surface pasteurization) and nonthermal physical treatments (dehairing, UV light, pulsed light, electric pulse fields, and packaging), as well as the application of antimicrobials (alcide [acidified sodium chlorite], cetylpyridinium chloride, ozone, and hydrogen peroxide).

Thermal Physical Treatments

Desiccation

In a recent study, it was demonstrated that using rapid desiccation with dry heat before inoculation and after water washing was more effective than water washing alone for the immediate reduction of bacterial populations on beef surfaces (Cutter et al., 1997). In these experiments, rapid desiccation with heat was performed on beef shortplates with a forced-air, propane heater applied at

Table 1. A variety of alternative antimicrobial interventions (Taken from: Federal Register, volume 61, July 25, 1996, p. 38855).

Interventions	
irradiation	pre-evisceration carcass washes
x-rays	water curtains
linear accelerators	counter current or counter flow scalders
high energy ultraviolet light	peroxi-bicarb process
pulsed light	warm fresh water rinses
sonic, infrasonic and ultrasonic emitters	ozonated water
copper sulfate pentahydrate	steam pasteurization
chlorine dioxide	steam vacuuming
hydrogen peroxide	hot wax dipping
singeing	

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This presentation is dedicated to the memory of my advisor, Dr. Donald M. Kinsman (1923-1998), Professor Emeritus, College of Agriculture and Natural Resources, University of Connecticut, Storrs, CT.

Names are 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.

Table 2. Source of information for development of new technologies (Taken from: Federal Register, volume 61, July 25, 1996, p. 38855).

Information	Publication
Guidelines for preparing and submitting experimental protocols to FSIS for use by establishments wishing to conduct trials of new technologies and procedures	Federal Register, volume 60, p. 27714, May 25, 1995
Guidelines for establishments to use for submitting written proposals and protocols for approval to conduct experiments	FSIS Directive 10,700.1
Proposed rule to facilitate the review and approval of substances intended for use in or on meat and poultry products	Federal Register, volume 60, p. 67459, December 29, 1995

300°C or 400°C for up to 25 seconds and water washing (125 psi, 15 seconds, 35°C) with a carcass washer specifically designed for research purposes. In the first set of experiments, several combinations of desiccation (400°C) and water washes were examined. Beef surfaces that were desiccated for 15 seconds, contaminated with feces containing pathogens, water washed, and desiccated again for 30 seconds resulted in undetectable levels of the organisms *Escherichia coli* O157:H7, *Salmonella choleraesuis* subsp. *choleraesuis* serotype Typhimurium (*S. typhimurium*), *Listeria innocua,* or *Clostridium sporogenes*. Other experiments were conducted with less heat (300°C) for shorter times to minimize moisture loss and discoloration. When pre-inoculation desiccation for 10 seconds was combined with water washing and a 25-second post-wash desiccation step, aerobic bacteria, coliforms, and *E. coli* biotype 1 associated with the carcass surface were reduced by greater than 4 $\log_{10}$ CFU/cm^2 (Cutter et al., 1997). It was speculated that the use of desiccation on the carcass surface at two points in the slaughter process (immediately after hide removal and again after water washing) could serve two functions. First, desiccation before inoculation appeared to dehydrate the carcass surface and shrink the connective tissue components. Shrinkage and dehydration may affect how bacteria attach to the carcass surface and ultimately, their removal during water washes. Second, desiccation also could provide a rapid and an economical means of generating both dry and moist heat in order to reduce bacteria remaining on the carcass surface (Cutter et al., 1997).

Surface pasteurization

The use of steam or moist heat interventions for beef, pork, and lamb carcasses is well documented and has been implemented in the meat industry (Dorsa, 1997). Recently, a steam process has been developed for use with poultry carcasses and has the potential to be used on retail pieces of beef, pork, or lamb. In this system, meat surfaces are treated with: 1) a vacuum to remove surrounding air, 2) absorbed gas with low temperature steam, 3) thermally saturated steam, and 4) evaporative cooling by exposure to a vacuum (Morgan et al., 1996a,b). Initial studies indicated that chicken meat surfaces inoculated with *L. innocua* exhibited an approximately 4 $\log_{10}$ reduction following treatments with this system and did not appear to be cooked (Morgan et al., 1996a). Subsequent experiments involved optimization of various parameters (steam time, vacuum time, flush time, steam temperature, surfaces; Morgan et al., 1996b). Based on this study, application of 121°C steam for 48 milliseconds effectively reduced populations of *L. innocua* 4.0, 2.8, 2.4, 2.5, and 1.9 $\log_{10}$ units on fresh chicken meat, frozen and thawed chicken meat, frozen and thawed chicken skin, fresh lean beef, and fresh lean pork, respectively (Morgan et al., 1996b). Because of the relatively short exposure time required for carcasses in this system (<1 second), surface pasteurization could be used in a processing line to treat 3600 birds/hour, or a similar number of other meat products (Morgan et al., 1996b). Currently, researchers are investigating the feasibility of this system to reduce bacterial contamination on steaks, chops, and roasts (personal communication, Mike Kozempel, USDA-ARS, ERRC, Wyndmoor, PA).

Nonthermal Physical Treatments

Dehairing

The objective of chemical dehairing is to remove hair, mud, feces, soil, and other external contamination before the hide is removed in order to reduce bacterial and visible contamination further in the slaughter process (Schnell et al., 1995). Chemical dehairing of meat animal carcasses involves a twelve step process that is begun immediately after exsanguination (Bowling and Clayton, 1992). Following an initial water wash, the carcass is: i) subjected to an application of 10% sodium sulfide (total contact time, 180

seconds); ii) water washed; and iii) neutralized by treating with 3% hydrogen peroxide and water washes (Schnell et al., 1995). After these steps, the carcass then undergoes normal dehiding, eviceration, and chilling procedures. Schnell et al. (1995) demonstrated that while the chemical dehairing process did not reduce the generic aerobic bacterial population more than normally-processed controls, it did reduce the amount of visible contamination on beef carcasses. In another experiment, *L. monocytogenes, E. coli* O157:H7, and *S. typhimurium* suspended in bovine feces were inoculated onto the hides of beef carcasses, subjected to the twelve-step dehairing process, and remaining bacterial populations enumerated (Graves Delmore, et al., 1997). Bacterial populations were reduced greater than 6, 4, 3, and 3 $\log_{10}$ CFU/cm^2 for coliforms, *E. coli* O157:H7, *L. monocytogenes*, and *S. typhimurium*, respectively (Graves Delmore, et al., 1997). Currently, a custom-designed dehairing system is being installed in a commercial slaughterhouse in order to provide a more representative picture of contamination present on carcasses following the dehairing process (Sofos, 1998).

Ultraviolet light

Because of limitations with regard to exposure level on food surfaces and technological problems, ultraviolet (UV) light has been used primarily in the food industry for disinfection of air, liquid foods, packaging, and water (Farkas, 1997). UV light is effective against bacteria because of the irreparable damage to nucleic acids (Farkas, 1997). The control of microbial contamination on meats by UV light has been utilized since the 1940's as a means of extending shelf life (Korhonen et al., 1981). Beef, lamb, sheep, and poultry carcasses, fish, and beef slices have been subjected to UV light (254 nm) for a short duration, several days or even weeks (Huang and Toledo, 1982; Kaess and Weidemann, 1973; Korhonen et al., 1981; Wallner-Pendelton et al., 1994; Yndestad et al., 1972). The general findings from these studies indicated that while specific populations of organisms can be reduced (i.e., *Salmonella* spp.) by UV light treatments, shelf life extension was only minimal (Huang and Toledo, 1982; Korhonen et al., 1981; Wallner-Pendelton et al., 1994;).

Recently, a patent was issued (Newman, 1997) for a method of sterilizing entire food surfaces by UV treatment at approximately 265 nm. Commercially available as Select^{UV}®, this process claims an extension of shelf life in fish, chicken, gas flushed pork loin, and tenderloin. In vacuum packaged pork, a microbial reduction of greater than 99% was observed for *S. typhimurium., L. monocytogenes*, *E. coli* O157:H7, *Staphylococcus aureus* coliforms, and *Campylobacter jejuni* (manufacturer's information). In addition to microbial reductions, no pigment changes or lipid oxidation occur because of the wavelength band used (manufacturer's information). The technology has been designed for 'in-line' treatments of whole pork, lamb, and beef carcasses, trim, or subprimals. Since the technology is contained within its own stainless steel chamber, it is environmentally safe and there are no operational employee hazards (manufacturer's information). Additional manufacturer's information indicates that this technology is approved for use by FDA, USDA, and FSIS.

Pulsed Light

As mentioned in the previous section, UV light at wavelengths of 254 or 265 nm is effective for reducing some bacterial populations on meat surfaces. Recently, scientists have discovered that the use of white light flashes, at an intensity 20,000 times that of sunlight, may also be an effective technology for reducing microbes on muscle foods (Dunn et al., 1995). Known as PureBright®™, an intense flash of light lasting for only a few hundred microseconds is generated in a specially designed instrument at a wavelength of 200 nm in the UV spectrum to about 1 mm in the near-infrared range. The spectral distribution demonstrates peak emission between 400 and 500 nm and these wavelengths are in the nonionizing portion of the electromagnetic spectrum (Dunn et al., 1995).

PureBright®™ has been demonstrated to be effective against pathogens on a wide range of muscle foods. Researchers have reported a 1 to 3 $\log_{10}$ reduction of *Salmonella* spp. and *Listeria innocua* on chicken wings and frankfurters, respectively (Dunn et al., 1995). When combined with other hurdles such as hot water rinses, beef steaks treated with the pulsed light demonstrated significantly fewer *E. coli* O157:H7 per square centimeter than hot water washes alone (Joseph Dunn, personal communication). Under standard retail packaging, PureBright®™ also extended the shelf life of vacuum packaged beef steaks. On beef carcass surfaces, the application of PureBright®™ after spray washes with water or acetic acid significantly reduced populations of *S. typhimurium* and *E. coli* O157:H7, as compared to controls (Joseph Dunn, personal communication). The approximate cost of this technology is $0.08 per carcass. As of 1997, the FDA had been petitioned for the use of pulsed light in food processing (Hoover, 1997).

Pulsed electric fields

Use of pulsed electric fields (PEF) to reduce bacterial populations on foodstuffs involves the use of short pulses of high voltage (Hoover, 1997; Wouters and Smelt, 1997). The inactivation mechanism of PEF against bacterial cells is accomplished by the creation of pores in the cell membrane, the subsequent leakage of cellular constituents, and ultimate, cell death (Farkas, 1997; Wouters and Smelt, 1997). The effectiveness of PEF is determined by temperature, microbial growth stage, voltage intensity, duration of pulse, and resistivity of suspension material or food. Because of the makeup of the cell membrane, gram positive bacteria are less sensitive to PEF than gram negative bacteria; therefore, other interventions may be needed to effect reductions of these organisms (Farkas, 1997).

One of the first documented reports addressing the effects of PEF against bacteria on meat surfaces was by Raccach and Hendrickson (1978). In that study, researchers using electrical stimulation to improve the tenderness of beef noticed that the lag phase of psychrotropic bacteria was extended and the shelf life of the treated carcasses was prolonged by three days, as compared to controls. Since then, several additional studies have addressed the reduction of microorganisms with PEF, alone or in combination with antimicrobials. Dickson and Crouse (1989) demonstrated that populations of *Salmonella* spp. on beef treated with PEF were reduced approximately 0.50 $\log_{10}$, as compared to controls. Bawcom et al. (1995) determined that pulsed electrical currents were effective for reducing populations (0.7 $\log_{10}$) of *Salmonella* spp. associated with beef steaks. Tinney et al. (1997) demonstrated that *E. coli* O157 and *S. typhimurium* could be effectively reduced by greater than 0.50 $\log_{10}$, as compared to controls, when 2% acetic acid sprays were combined with PEF. The use of PEF in combination with sodium chloride, sodium bicarbonate, or trisodium phosphate also resulted in a reduction of approximately 1 $\log_{10}$ of *S. typhimurium* on chicken skin (Li et al., 1994). Based on these studies, it appears that the application of electricity can be used alone or in combination with other interventions as a way to reduce bacterial contamination on muscle foods.

Packaging

For fabricated or further processed muscle foods, the use of vacuum or modified atmosphere packaging as an intervention to improve stability and safety is well documented (for reviews, see Church and Parsons, 1995; Farber, 1991; Garcia et al., 1995; Genigeorgis, 1985; Hintlian and Hotchkiss, 1986; Labuza, et al., 1992; Lambert et al., 1991; Ooraikul and Stiles, 1991). Recent information also suggests that edible gels/films/coatings made from lipid, polysaccharide, or protein components may serve as a potential intervention of microbial growth on fabricated muscle foods (for a review see Gennadios et al., 1997). In both cases, edible and plastic derived packaging materials have been shown to improve the quality and safety of a wide variety of fresh and processed muscle foods by reducing moisture loss, minimizing lipid oxidation, preventing discoloration, reducing drip, controlling levels of spoilage or pathogenic microorganisms, and as a way to retain activity of food additives such as antimicrobials or antioxidants (Gennadios et al., 1997). Edible packaging materials are also being specifically developed as a way to improve mechanical handling, reduce environmental waste, and utilize otherwise discarded agricultural commodities (Gennadios et al., 1997).

The application of antimicrobials in combination with packaging materials is currently receiving considerable attention as a potential intervention for a variety of muscle foods. Meyer et al. (1959) were among the first researchers to demonstrate that antibiotics and antifungal compounds could be added to a carageenan film to reduce bacteria by 2 $\log_{10}$ on poultry. Siragusa and Dickson (1992, 1993) demonstrated that organic acids were more efficacious for reducing levels of *L. monocytogenes, S. typhimurium*, and *E. coli* O157:H7 when immobilized in calcium alginate and applied to beef carcass tissue than when these compounds were applied alone. Baron (1993) demonstrated that potassium sorbate and lactic acid could be incorporated into an edible cornstarch film to inhibit *S. typhimurium* and *E. coli* O157:H7 on poultry. Cutter and Siragusa (1996, 1997) reported that immobilization of the bacteriocin nisin in calcium alginate gels not only resulted in greater reductions of bacterial populations on lean and adipose beef surfaces, but also resulted in greater and sustained bacteriocin activity when the tissues were ground and stored under refrigerated conditions for up to 7 days, as compared to nisin-only controls. Dawson et al. (1996) demonstrated that nisin and lysozyme could be incorporated into edible heat-set and cast films made from corn zein or soy protein and exhibit activity against *E. coli* and *Lactobacillus plantarum.* The results of this type of research highlight the potential for incorporating antimicrobial peptides with a wider and different range of inhibitory activity directly into packaging materials for use in controlling food spoilage as well as enhancing microbial safety.

Application of Antimicrobials

Sanova™

A system known as Sanova™, Food Quality System, (Alcide™ a division of Novus™ International, Inc., St. Louis, MO), has been recently approved by USDA for use in poultry slaughter plants. The antimicrobial compound of Sanova™ is chlorous acid which is formed when sodium chlorite is acidified with citric acid. Chlorous acid disrupts the bacterial membrane function leading to the death of the organism; it is bactericidal with no evidence of injury and recovery (Charles Schasteen, Novus International, Inc., personal communication). In preliminary trial applications, a spray cabinet was devised to deliver Sanova™ to poultry carcasses at two points in the slaughter line (inside/outside bird washer and before the chiller). A nine second application delivered approximately five ounces of Sanova™ to the carcass surface. Resulting bacterial populations from these treatments were compared to poultry carcasses that had undergone standard chlorination in the chiller. Both immediate and sustained reductions of biotype 1 *E. coli* and *Salmonella* spp. were evident on carcasses following treatments with Sanova™ and 9 days of storage at 4°C (Charles Schasteen, personal communication).

Additional information indicates that spray application of Sanova™ is effective against *S. typhimurium* and *E. coli* O157:H7 on beef surfaces. At initial populations of approximately 5 $\log_{10}$ units, treatments with Sanova™ (10 psi, 10 seconds) reduced pathogen populations on fecally contaminated beef surfaces greater than 4 $\log_{10}$ units. Sanova™

treatment can be applied to meat animal carcasses at a cost of approximately $0.01 per pound of treated meat (Charles Schasteen, personal communication).

Cetylpyridinium chloride

Cetylpyridinium chloride (CPC) is a water soluble, neutral pH, colorless and odorless compound that has been used for over 40 years in oral hygiene products including toothpaste, throat lozenges, and mouthwashes. Research in oral bacteriology has indicated that CPC found in some of these products reduces bacterial attachment and ultimately plaque formation on tooth surfaces (Renton-Harper et al., 1996). Because of its low surface tension and hydrophilic and lipophilic properties, CPC works well in wetting the skin and penetrating tissue (Huyck, 1944). CPC binds to and precipitates acidic mucopolysaccharides such as those found in chicken fascia; treatment of fascia with CPC prevents formation of a surface network of collagen fibers and reduces the number of bacteria retained during contamination experiments (Thomas and McMeekin, 1991). Recently, CPC was found to be efficacious for reducing populations of *Salmonella* spp., *C. jejuni, L. monocytogenes*, and *E. coli* O157:H7 on poultry carcasses (3 to 4 $\log_{10}$ reductions; Kim and Slavik, 1996; Li et al., 1997; Mastler, 1996). CPC also has exhibited residual activity on poultry surfaces such that cross contamination of *Salmonella* spp. between carcasses can be minimized (Breen et al., 1997).

In another recent study, *E. coli* O157:H7 and *S. typhimurium* experimentally inoculated onto beef shortplates and spray washed (125 psi, 15 s, 35°C) with 10 mg/ml CPC (Cutter and Dorsa, 1998), were reduced to virtually undetectable levels (0 $\log_{10}$ CFU/cm^2). Additionally, aerobic plate counts (APC) from fecally contaminated pre-rigor beef surfaces were reduced greater than 6 $\log_{10}$. Populations of pathogenic and aerobic populations also were inhibited or suppressed during 35 days of refrigerated, vacuum packaged storage. Selective enrichment of day 35 samples did not recover either of the pathogens. Preliminary sensory evaluation indicated that no unacceptable organoleptic properties (flavor, color, and texture) were detected when beef steaks were treated with 10 mg/ml CPC and cooked. The estimated cost of CPC treatment was less than $0.001 per pound or approximately $0.17 per carcass. The results of this study demonstrate that antimicrobial spray treatments with CPC may be effective for reducing both aerobic and pathogenic bacteria, thereby improving the microbiological safety, stability, and overall quality of beef products (Cutter and Dorsa, 1998).

Ozone

Ozone, a powerful oxidant, is produced by passing gaseous oxygen through a high voltage electrical field at ambient or refrigerated temperatures (Graham, 1997; Horvath, et al., 1985). The resulting gas is a more effective sanitizer than chlorine and is being used for water disinfection, control of post-harvest decay of fruits and vegetables, and container sterilization for beverages (Horvath et al., 1985; Graham, 1997). It has been proposed that ozone inhibits bacteria by attacking proteins or lipids of bacterial cell walls or membranes, oxidizing sulfhydryl groups of bacterial enzymes, or by modification of the purine and pyrimidine bases of nucleic acids (Greene, et al., 1993). Several studies (for a review, see Rice et al., 1982) have examined the efficacy of gaseous ozone treatments for the inactivation of bacteria on the surface of a variety of muscle foods including fish (Horvath, et al., 1985) and beef (Kaess and Weidemann, 1968a,b). In all instances, this compound was found to be effective in reducing populations. However, because of the human health hazards associated with exposure, direct application of gaseous ozone in the food industry is limited. An alternative, ozonated water, is an effective decontaminating agent and can be generated without the ramifications associated with gaseous ozone.

In several studies, the efficacy of aqueous ozone (ozonated water) was determined against different bacterial populations. One study demonstrated that bacteria were reduced approximately 5 log units in ozonated water without the addition of compounds used to simulate organic load (soluble starch or bovine serum albumin; Restaino et al., 1995). The presence of 20 ppm soluble starch or bovine serum albumin significantly affected the concentration of ozone in deionized water and ultimately, the effectiveness of the compound against the test organisms, except *S. typhimurium* and *E. coli* (Restaino et al., 1995). Greene et al. (1993) demonstrated reductions of approximately 5.6 and 4.4 $\log_{10}$ CFU/cm^2 against *Pseudomonas fluorescens* and *Alcaligenes faecalis*, respectively, on stainless steel surfaces (Greene, et al., 1993). The results from both of these studies indicate that aqueous ozone is effective for destroying surface-attached bacteria, especially in the presence of high organic material.

Chen et al. (1987) demonstrated that aqueous ozone (5° C) was effective against bacteria in suspension, but ineffective against the organisms attached to shrimp meat. Yang and Chen (1979) and Sheldon and Brown (1986) also demonstrated the effectiveness of aqueous ozone as a disinfectant of poultry carcasses. Specifically, aqueous ozone was found to extend the shelf life of broiler parts after refrigerated storage by 2.4 days (Yang and Chen, 1979) as well as reduce aerobes and psychrotrophs on chilled carcasses (Sheldon and Brown, 1986).

Recently, several reports have addressed the use of aqueous ozone for decontamination of beef carcasses. At concentrations of 0.3 or 2.3 ppm, aqueous ozone reduced aerobic plate counts to 1.3 $\log_{10}$ CFU/cm^2 from fecally contaminated beef carcasses when starting populations were greater than 4 $\log_{10}$ CFU/cm^2 (Reagan et al., 1996). Gorman et al. (1995) demonstrated that spray washing with water, followed by 0.5% aqueous ozone, effectively re-

duced aerobic plate counts to 2.33 $\log_{10}$ CFU/cm^2 when initial populations were 6.66 $\log_{10}$ CFU/cm^2.

Recently, aqueous ozone was granted GRAS status (Federal Register, 1997. Title 21, Volume 3, Section 184.1563) by the FDA. Numerous commerical units are currently available to generate aqueous ozone for direct application to muscle foods. In using these systems, aqueous ozone is applied to muscle food surfaces at very low pressures (10-20 psi) from 15 to 300 seconds (personal communications; John McFarlane, Cyclopss Corporation, Salt Lake City, Utah; Ron Long, TruPure Ozone Technologies, Yreka, California). In using aqueous ozone, manufacturers are demonstrating significant reductions (3-4 $\log_{10}$ units) of *E. coli* O157:H7 and *Salmonella* spp. on muscle food surfaces.

Hydrogen peroxide

The antimicrobial, hydrogen peroxide has long been recognized for its bactericidal properties (for a review, see Davidson et al., 1983). The mode of action of this compound against bacteria is its oxidizing effect on the bacterial cell, presumably due to the reaction of the compound with cell proteins and destruction of their basic molecular structure (Davidson et al., 1983).

The direct addition of hydrogen peroxide, alone or in combination with other compounds for decontaminating muscle foods has been well documented. Lillard and Thomsen (1983) determined that the use of 6,600 ppm of hydrogen peroxide as a bactericide in poultry chiller water reduced aerobic bacteria and *E. coli* by greater than 95% and 99.9%, respectively. At 11,000 ppm of hydrogen peroxide, aerobic bacteria and *E. coli* on poultry carcasses were reduced 94% (Lillard and Thomsen, 1983). Reagan et al. (1996) determined that a 5% concentration of hydrogen peroxide applied by spray washing to fecally contaminated beef surfaces (initial aerobic population greater than 4 $\log_{10}$ CFU/cm^2) reduced bacteria to 1.14 $\log_{10}$ CFU/cm^2. Gorman et al. (1995) demonstrated that spray washing with water, followed by a 5% hydrogen peroxide wash effectively reduced aerobic plate counts to 1.33 $\log_{10}$ CFU/cm^2 when initial populations were 6.66 $\log_{10}$ CFU/cm^2. Kochevar et al. (1997) also examined the application of 5% hydrogen peroxide spray washes against fecally contaminated lamb carcasses. When applied, a 5% hydrogen peroxide concentration reduced initial populations of 4.83 $\log_{10}$ CFU/cm^2 to 2.71 $\log_{10}$ CFU/cm^2 (Kochevar et al., 1997).

The application of hydrogen peroxide with other antimicrobials also has been investigated. A patent was issued to address the effect of a combination of sodium bicarbonate and hydrogen peroxide to remove foreign material and reduce bacterial populations on poultry carcasses (O'Brien, 1987). Fletcher et al. (1993) evaluated this combination on broiler carcasses and found that a spray regimen consisting of 2% sodium bicarbonate (5 seconds), a water rinse, and 3% hydrogen peroxide (5 seconds) did not reduce total plate counts immediately after treatment, but did reduce counts by 0.30 $\log_{10}$ after 7 days of refrigerated storage. In another experiment, fat and lean beef carcass tissues were experimentally inoculated with sterile feces containing approximately 5 $\log_{10}$ CFU/cm^2 of gram positive and gram negative bacteria (Bell et al., 1997). Spray washes with water, 1% acetic acid, 3% hydrogen peroxide, or 1% sodium bicarbonate were not as effective for reducing bacterial populations as the combination of acetic acid followed by hydrogen peroxide. All organisms were reduced greater than 99.9% on either tissue type (Bell et al., 1997). Based on the results of this study, spray wash treatments consisting of the right combination of antimicrobials can be more effective than single applications for reducing undesirable bacteria on beef surfaces (Bell et al., 1997).

Conclusions

While the general microbial load of carcass and muscle food surfaces is intrinsically low, unavoidable and accidental contamination can occur throughout post-harvest production, including slaughter, fabrication, or further processing. As discussed in this paper, the integration of newly discovered- and previously established-thermal or nonthermal post-harvest interventions or antimicrobial spray washes at various steps in the process may provide improvements to the microbial stability, quality, and safety of the final muscle food product.

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