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PROCESSES TO REDUCE CONTAMINATION WITH PATHOGENIC MICROORGANISMS IN MEAT

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Abstract

Live animals and the environment serve as sources of pathogenic microorganisms, which contaminate carcasses during the slaughtering process and meat products during processing, storage and handling. A variety of processes have been developed with the objective of reducing contamination on carcasses and subsequent meat products. These decontamination processes include animal cleaning, chemical dehairing at slaughter, spot-cleaning of carcasses before evisceration by knife-trimming or steam and vacuum, spraying, rinsing, or deluging of carcasses before evisceration and/or before chilling with water or chemical solutions (e.g., organic acids, trisodium phosphate, etc.) or steam. The processes are applied at various concentrations or intensities, pressures (2-20 bar), temperatures (15-80 °C) and for different lengths of time (5-20 sec), individually or in sequential combinations. Decontamination interventions are used extensively in the United States and they are integrated into food safety management systems, such as hazard analysis critical control point (HACCP), which is required by regulation. Application of decontamination processes assists in meeting regulatory microbiological performance criteria and should contribute in enhancement of product safety, provided that chilling, cutting, processing, storage, distribution and preparation for consumption are also performed properly and under hygienic conditions.

Introduction

Animal products, including carcasses and fresh meat, are easily contaminated with microorganisms and support their growth if not properly handled, processed and preserved. Extensive contamination, or abusive conditions of handling and storage that allow microbial proliferation, increase the potential for presence of pathogenic bacteria and formation of toxins, and may lead to product spoilage and public health problems (Sofos, 1994; Sofos et al., 1999d). A variety of sources, including air, water, soil, feces, feed, hides, intestines, lymph nodes, processing equipment, utensils and humans, contribute to the microbial contamination of the sterile muscles of healthy animals during slaughter, fabrication, and further processing and handling (Bell, 1997; Gill, 1998; Sofos, 1994). The types and extent of contamination depend on sanitation procedures, hygienic practices, product handling and processing, application of decontamination interventions, and conditions of storage and distribution. Contamination with spoilage microorganisms may lead to product and economic losses, while presence of pathogens or their toxins may be the cause of foodborne disease that may lead to loss of human life (Sofos, 1994).

Highly publicized outbreaks of foodborne disease caused by pathogens, such as *Escherichia coli* O157:H7 and *Listeria monocytogenes*, have increased consumer concerns and interest in food safety (Sofos and Smith, 1993). In response, regulatory authorities, academic research institutions and the industry have undertaken efforts to apply interventions and food safety management systems to improve the microbiological quality of meat. Specifically, the Food Safety and Inspection Service (FSIS) of the United States Department of Agriculture (USDA) has implemented regulatory requirements such as knife-trimming for removal of all visible physical contaminants from beef carcasses prior to washing and chilling; the establishment of sanitation standard operating procedures; operation under the hazard analysis critical control point (HACCP) system; and, establishment of microbiological performance criteria and standards for *Escherichia coli* biotype I and *Salmonella* as a means for verification of HACCP (FSIS, 1996; Sofos, 1993). In turn, the industry is implementing decontamination interventions to meet these regulatory requirements and to improve the microbiological condition of meat (Dickson and Anderson, 1992; Dorsa, 1997; Sofos, 1994, 1998a,b; Sofos and Smith, 1998a,b, 1999; Sofos et al., 1999a,b,c). In this paper we discuss sources and extent of microbiological contamination of fresh meat, and the importance of animal cleanliness, sanitation, hygienic practices and carcass decontamination processes in reducing presence of pathogens in fresh meat.

Sources and Extent of Contamination

Animal contamination: Live animals are often highly contaminated, or are asymptomatic carriers of pathogenic bacteria (Fedorka-Cray et al., 1998; Hancock et al., 1997; Letellier et al., 1999; Skerve et al., 1998), and can serve as sources of subsequent meat contamination. Animal cleanliness is influenced by climate, geographic location, method of transportation and holding conditions. For example, animals raised on pastures may carry more bacteria of soil origin, while microorganisms of intestinal origin may be more common on carcasses from animals finished in feedlots (Sofos, 1994; Sofos et al., 1999d). Every feasible effort should be made to prevent accumulation of excess mud and dung on the animals, because it may introduce bacterial pathogens into the plant environment. In our studies (Sofos et al., 1999a), we have found that, on the average, feces of steers and heifers were more often (8.3-14.2%) contaminated with *Salmonella* than those of older cows and bulls (4.4-10.0%). In contrast, external dry soil (dunglocks) was more often positive for *Salmonella* in cows and bulls (7.8-12.2%) than in younger steers and heifers (0.8-7.5%). Furthermore, it was determined that the larger the amount of mud on the hide of steers and heifers, the higher the incidence of *Salmonella* (1.0% positive for mud score of 0; 4.0% for mud score of 1; 8.5% for mud score of 2; and, 11.1% for mud score of 3). Cows and bulls had an average *Salmonella* incidence on the hide of 7.4-13.3%, irrespective of mud score (Sofos et al., 1999a). In another study (Kain et al., 1997), we found that in cull dairy cows, incidence of *Salmonella* in fresh and dry external feces was 0 and 13.8%, respectively, while no *E. coli* O157:H7 was detected in the feces. Incidence of *E. coli* O157:H7, is usually ≤5% in feces of cattle (Sofos et al., 1998).

Therefore, there is a need to determine risk factors in order to develop management practices that will help in the control of the prevalence of pathogens in animals and their products. Factors to be considered include animal fasting, feeding and stressing practices such as those applied during confinement and transportation, amount of roughage and other dietary components, animal cleanliness, etc. (Cray et al., 1998; Dargatz et al., 1997; Diez-Gonzalez et al., 1998; Hadley et al., 1997; Herriot et al., 1998; Jordan and McEwen, 1998; van Donkersgoed et al., 1997).

Carcass contamination: In general, the muscles of live healthy animals are sterile, while lymph nodes, some organs, and, especially, surfaces exposed to the environment, such as external hide, pelt, or fleece, the mouth and the gastrointestinal tract carry extensive contamination (Gill, 1998; Sofos, 1994; Sofos et al., 1999d). These are major sources of plant, carcass and meat contamination during slaughtering and processing. Recent studies have examined contamination of carcasses with various microorganisms ((Sofos et al., 1999a,b,c) and the data are useful in establishing baseline levels and contamination sources in order to determine future progress as decontamination programs are implemented. The results of our studies from seven plants demonstrated that beef carcass contamination may vary with season, plant design and operation, geographic area, location within the plant, and, to some extent, anatomical carcass site (Sofos et al., 1999a,b,c). Overall, levels of carcass contamination after 24 hours of carcass chilling were 2.55, 0.27 and 0.12 log colony forming units (CFU)/cm^2 for aerobic plate counts, total coliform counts and *Escherichia coli* counts. In one of our studies (Sofos et al., 1999e) we recovered 0.7% and 1.7% *Salmonella* positive samples by carcass swabbing with sponges or by excising, respectively. Incidence of *E. coli* O157:H7 is reported as 0.2% and 0.1% for carcasses and ground beef, respectively, in the United States (Sofos et al., 1998). Anecdotal reports of incidences as high as 10% in raw beef also exist. Average *Salmonella* incidence of 0.3-1.1% and 1.1-2.6% on steer/heifer and cow/bull carcasses was determined in our studies (Sofos et al., 1999c).
We have also determined baseline contamination levels of pork carcasses in 12 plants (Zerby et al., 1998a). Mean bacterial counts were lower for carcasses from plants that slaughtered market hogs compared to sows, and were similar in the summer season between plants that scalded and skinned; in the winter season, counts were lower for plants that scalded compared to those that skinned the carcasses. Overall incidence of *Salmonella* was 3.2% and 5.5% for a two (belly, jowl) and a three site (belly, jowl and ham) sampling protocol, while incidence of *Campylobacter jejuni/coli, Yersinia enterocolitica, Yersinia* spp., *Listeria monocytogenes and Listeria* spp. (three carcass sites) was 8.5%, 0.9%, 14.5%, 3.1% and 12.1%, respectively (Zerby et al., 1998a).
In a study that attempted to correlate live cattle characteristics with carcass contamination we found that factors such as extent of mud presence on animal hide, manure wetness, ambulatory score and body condition of live animals had no major influence on bacterial counts of resulting carcasses (Kain et al., 1997). Another study (van Donkersgoed et al., 1997) also found that neither lot tag score nor plant lot tag score was associated with carcass bacterial counts. Thus, it appears that, although animals are a source of pathogen contamination for meat, slaughter operations play a major role in controlling the extent of such contamination. Individual plants need to determine procedures that will assist in consistently processing carcasses and meat of low microbial contamination.

Edible offal contamination: Variety meats (edible offal) may carry a higher level of microbiological contamination than other meat animal tissues, either by nature and origin, or due to poor hygienic and chilling conditions (Gill, 1998). We have found that bacterial counts in most of 17 types of beef variety meats examined from six plants increased between packaging and chilling, indicating the inefficiency of the chilling process (Delmore, 1998). Average total coliform counts for various offal products before and after chilling were 1.3-3.4 and 2.0-3.9 log CFU/g, respectively. Pathogen incidence in the 830 samples, examined only after chilling, was 0% for *E. coli* O157:H7, 0.8% for *Salmonella* and 4.5% for *L. monocytogenes*. Pork variety meats (11 types) were examined for microbiological contamination in 10 plants (Zerby et al., 1998b). In contrast with beef edible offal, aerobic plate counts, total coliform counts and *E. coli* counts did not increase during chilling of pork variety meats. Average coliform counts were 2.0-4.6 and 1.7-4.1 log CFU/g before and after chilling, respectively. Incidence of pathogens in the 405 samples of pork edible offal analyzed was 0% *Y. enterocolitica*, 1% *C. jejuni/coli*, 15% *Salmonella* and 16% *L. monocytogenes*. During these studies, we developed a set of good manufacturing recommendations that will be beneficial in improving the microbiological quality of the products.

Processes To Reduce Contamination

Animal cleaning: One, seemingly obvious, approach that may contribute to the reduction of external animal contamination, and subsequently, carcass contamination is to clean or wash the hide of the animals before slaughter and dressing. Pre-slaughter washing of sheep has been practiced in New Zealand (Biss and Hathaway, 1996), while, partial or complete, washing of cattle before slaughter has been used by some plants in the United States. Individual operations have evaluated, or applied interventions, such as removal (by cutting or shearing) of hair and fecal tags from the exterior of the animals or washing of animals before slaughter, but in many instances the results are generally less than promising (Gill, 1998). In general, animal washing before slaughter has variable influence on carcass contamination. Furthermore, application of the procedure may be limited by climate, type of animal, and availability of facilities (Sofos and Smith, 1998a). United States regulatory guidelines require cattle to be dry, or at least not dripping, when they are slaughtered (Reed, 1996), which can be a constraint when animal washing is considered before slaughter. However, when animals are wet or excessively soiled, slaughter speeds should be reduced to minimize accidental transfer of contamination from the exterior of the animals onto the carcass or the plant environment. In addition, modifications in the steps involved in hide removal, or in equipment used for hide removal, may help in minimizing transfer of contamination onto the carcass surface (Hadley et al., 1997). One approach that may help in the reduction of carcass contamination with pathogens may be to process highly contaminated or infected animals separately from cleaner or pathogen-free herds (Gill, 1998). This approach, however, may be impractical in some systems of animal production, marketing, distribution, and slaughtering, or for control of more than one type of pathogenic microorganisms on the same animals. Nevertheless, highly soiled animals are an important potential source of plant contamination, and presentation of clean animals for slaughter is desirable because it reduces the likelihood of pathogen presence and

transfer onto carcasses (Bolton et al., 1998). However, poor sanitation, hygiene and manufacturing practices during slaughtering, fabrication and processing can lead to excessively contaminated meat, even when less heavily soiled animals are processed.

Chemical dehairing: A patented process (Bowling and Clayton, 1992), for chemical dehairing of cattle early during slaughter, has been proposed for use, with the objective of removing hair, mud, manure and other external contaminants before hide removal, and, thus, to minimize carcass and plant contamination from these sources (Sofos and Smith, 1998a). The process was applied experimentally at the post-exsanguination stage in a commercial beef slaughtering operation and the resulting carcasses were compared with those from conventionally (not dehaired) processed animals (Schnell et al., 1995). It was found that dehairing reduced visible contaminants on the carcasses and the amount of knife-trimming needed to meet regulatory inspection requirements. Application of the dehairing process to hide samples in laboratory experiments (Castillo *et al.*, 1998a; Graves Delmore et al., 1997b) caused significant reductions in inoculated *E. coli* O157:H7, *Salmonella* spp. and *L. monocytogenes*. In addition to inactivation, however, the dehairing process also resulted in injured bacterial cells (Graves Delmore et al., 1997b), which may be of concern during subsequent product storage, if they repair their injury. Overall, it can be postulated that the bacterial status of dehaired carcasses could be improved in facilities designed for the exclusive processing of dehaired animals (Sofos and Smith, 1998a). It is anticipated that removing the dirt, feces, and hair in a separate room and prior to removing the hide should decrease the occurrence of pathogens on beef carcasses. It should be noted, however, that contamination of the resulting meat will also depend on plant design, good manufacturing practices, sanitation and hygienic practices, and overall avoidance of environmental cross-contamination. The issue of waste (hydrolyzed hair and dehairing chemical residues of sodium sulfide and hydrogen peroxide) disposal needs to be resolved before this technology can be adopted (Sofos and Smith, 1998a).

Spot carcass decontamination: The beef slaughtering and dressing process in high output operations consists of a sequence of more than thirty operations, often involving hundreds of workers. Some operations, especially those associated with hide removal (skinning), result in external contamination of carcasses and of the plant, and in cross-contamination and redistribution of microorganisms from heavily contaminated to cleaner parts of the carcass. Knives are used manually to remove visible soil and bruised tissue during the dressing process, especially following carcass splitting. Proper removal of soiled tissue should result in reduction of microbial contamination (Gorman et al., 1995a,b,1997; Hardin et al., 1995; Kochevar et al., 1997a,b; Reagan et al., 1996; Sofos, 1998a,b; Sofos and Smith, 1998a,b). Certain studies, however, have questioned the contribution of routine carcass trimming in reducing overall carcass contamination in commercial operations (Gill, 1998; Gill et al., 1996; Jericho et al., 1993). Nevertheless, trimming with a knife to remove visible contamination on carcasses is required under the "zero tolerance" policy in the United States. As an alternative, the FSIS has approved the use of the process of steam-vacuuming carcasses (spots <2.5 cm in diameter) with hand-held equipment (Castillo *et al.*, 1999; Dorsa et al., 1996; Kochevar et al., 1997a). Steam-vacuuming uses hot water and/or steam to loosen soil and kill bacteria, followed by application of vacuum to remove the contaminants, and is now applied extensively by the United States animal slaughtering industry because it reduces the need for carcass knife-trimming.

Data collected during commercial application of steam-vacuuming indicated that removal of visible soil and reduction of bacterial counts achieved with either one of the two commercially available systems in the United States were at least as extensive as those achieved by knife-trimming (Kochevar et al., 1997a). The number of times of application (passes) and the total contact time differed depending on the extent of fecal contamination, ease of its removal, and speed of each application by the operator, and should affect decontamination efficacy. Overall, the effectiveness depends on employee diligence of application and operational status of the equipment. Irrespective of decontamination efficacy, knife-trimming and steam-vacuuming contribute to carcass cleanliness and aesthetic acceptability, but it should be stressed that they are applied only to specific carcass portions, generally those known to be heavily contaminated (Sofos and Smith, 1998a).

Carcass decontamination: Carcass contamination varies with season of the year, type of animal slaughtered, anatomical carcass site, and step in the dressing process. However, extent of carcass contamination is often influenced the most by variation among plants, including plant design, speed of slaughter and skill of operators (Gill, 1998; Mackey and Roberts, 1993; Sofos et al., 1999a,b,c). Application of decontamination processes on carcasses, during and following dressing, is generally regarded as an effective intervention to reduce contamination (Sofos, 1998a,b; Sofos and Smith, 1998a). Carcass decontamination processes are based on immersion, flooding, cascading, deluging, rinsing, or spray-washing with water or chemical solutions. They are applied to remove visible soil, such as residual hair, feces and bone dust in the majority of slaughter plants in the United States and other countries, such as Australia and Canada, and they may be designated as critical control points. The decontaminating efficacy of these treatments is influenced by water pressure, temperature, chemicals present and their concentration, time of exposure (which depends on speed of slaughter and length of the application chamber), method of application, and time or stage of application during carcass dressing (Bolder, 1997; Cutter et al., 1997; Gorman et al., 1995b; Morrison and Fleet, 1985; Reagan et al., 1996; Sofos, 1994, 1998a,b; Sofos and Smith, 1998a,b).

Application of spraying/rinsing treatments to carcasses may cause penetration of bacteria into the meat or spreading and redistribution on the carcass, depending on spraying pressure. Other concerns are associated with the influence of time before decontamination on bacteria attachment, biofilm formation and potential protection from exposure to the decontamination treatment and injuries to bacterial cells or development of resistance in bacteria during exposure to decontamination treatments such as acids and hot water or steam. Removal, rather than redistribution of bacteria on the carcass by spray-washing treatments can be effected through proper use of spraying nozzles (e.g., type, number, distribution, position, spraying angle, water output, and operation), spraying pressure and time, size of carcass, and overall design of the chamber and spraying system. In addition, use of decontamination interventions that may inactivate (e.g., hot water, steam, chemical solutions), rather than only remove,

contamination should lessen the concerns associated with potential spreading of bacteria or their penetration into the tissue (Sofos, 1998a,b; Sofos and Smith, 1998a,b). One concern associated with application of decontamination interventions, which needs to be investigated, is the potential selection and establishment of resistant organisms in the spraying cabinets and other parts of the plant (Sofos and Smith, 1998a). The length of time involved between hide removal/exposure to contamination and application of decontamination treatments may influence bacterial attachment and efficacy of bacterial removal by the decontamination interventions. Cabedo et al. (1996,1997) found that extent of decontamination by various spray-washing treatments decreased, as the time lapse between exposure of beef carcass tissue to contamination and application of the decontamination treatments increased. Spray-washing of beef carcasses before evisceration, which is practiced in some plants in the United States, may owe its efficacy to the fact that it removes contamination very quickly after removal of the hide, while bacterial and soil attachment is still minimal (Dickson, 1995; Sofos, 1998a; Sofos and Smith, 1998a). In general, it is believed that carcass decontamination interventions contribute to the production of carcasses with lower levels of contamination and that reduced incidence of enteric pathogens helps in meeting regulatory requirements during slaughter.

Chemical decontamination: Warm (50-55 °C) solutions of organic acids (1-3%), such as acetic and lactic, have reduced bacterial numbers on carcass tissue by 1-3 logs (Castillo *et al.*, 1998b; Gorman et al., 1995a, 1997; Hardin et al., 1995; Kochevar et al., 1997b; Reagan et al., 1996; Smulders and Greer, 1998; Smulders et al., 1986), and are used extensively in commercial beef slaughter in the United States, while they are not permitted in Europe. In the form of rinses, before chilling, they are found useful, especially in combination with preceding treatments of hot water spraying, and potentially as having a residual antimicrobial effect during storage. Potential concerns associated with the use of organic acids include selection of acid-resistant organisms that may increase product spoilage, undesirable effects on product appearance, and equipment corrosion concerns (Gill, 1998; Smulders and Greer, 1998).

In addition to organic acids, several other chemical solutions have also been proposed and tested for the decontamination of meat. They include common chlorine and chlorine dioxide, trisodium phosphate, hydrogen peroxide, sodium hydroxide, ozone, sodium bisulfate, sodium chloride, acidified sodium chlorite, nisin, potassium sorbate, cetylpyridinium chloride, etc. (Sofos and Smith, 1998a). Trisodium phosphate solutions have been approved for treatment of beef and poultry carcasses in the United States (Bender and Brotsky, 1992; Dickson et al., 1994; Kim and Slavik, 1994; Morris et al., 1997). Our studies (Cabedo et al., 1996; Gorman et al., 1995a, 1997) showed that spray-washing with trisodium phosphate reduced contamination of beef brisket tissue, and that it may inhibit bacterial attachment, thereby allowing easier bacterial cell removal by washing (Cabedo, 1995). Hydrogen peroxide and ozonated water, were also found to reduce bacterial counts in experimental trials (Cabedo et al., 1996; Gorman et al., 1995a; Reagan et al., 1996), but their use may be of concern due to their oxidizing effects on fat and muscle pigments. Approval, acceptance, and actual use of these and any other chemicals as decontamination interventions will depend on several factors, including safety, product quality, efficacy, adaptability, need for decontamination, and cost (Sofos and Smith, 1998a).

Thermal decontamination: Exposure of animal tissues to hot water (>70°C) has been found effective (1-3 log reductions) against spoilage as well as pathogenic bacteria, including *Salmonella, Y. enterocolitica, E. coli* O157:H7 and *L. monocytogenes* (Castillo et al., 1998b; Davey and Smith, 1989; Gorman et al., 1995a; Kochevar et al., 1997b; Smith, 1992). Reagan et al. (1996) found that hot water spray-washing of beef (74-87.8°C at the pipe, for 11-18 sec and with 1,310 - 2,413 kPa pressures) reduced bacterial counts by approximately 2.0 log cfu/cm,^{2} and achieved more consistent decontamination compared to knife-trimming, as indicated by the smaller standard deviations of average bacterial count reductions. Graves Delmore et al. (1997a) found that hot water rinsing, in addition to removing visible soil, reduced coliform counts by 1.3-1.8 log cfu/cm,^{2} while Cabedo et al. (1996) found that, even after exposure to contamination for 2 or 4 hours, hot water (74°C) was more effective in decontaminating beef tissue than other treatments. Commercial hot water decontamination (85°C, 15 sec) of hog carcasses in Canada was found to be consistent in reducing mean bacterial numbers (by approximately 2 logs) compared to untreated controls (Gill and Jones, 1998; Gill et al., 1995, 1997). A hot water commercial decontamination system has been developed in Australia and consists of an enclosed stainless steel decontamination cabinet (3.5 m in length) for beef sides, and a water handling and treatment system for recirculation. This hot water decontamination system reduced inoculated bacterial counts by 2.4-5.1 log cfu/25 cm^2, depending on initial inoculum (Sofos and Smith, 1998a). Reconditioning and reuse of water in all types of decontamination applications is a topic of great interest, and settling, filtering and decontamination (e.g., chlorine, heat) systems are being developed as adjuncts to carcass decontamination technologies (Sofos and Smith, 1998a). In addition to the recirculating hot water cabinets developed in Australia and Canada, a recirculating hot water rinsing cabinet has also been developed in the United States for treatment of carcasses. As indicated, application of hot water for meat decontamination may involve immersion or dipping of the product, cascading of sheets of hot water, rinsing at low pressures, or spraying at higher pressures. Each of these approaches has advantages and disadvantages. Immersion may be more applicable to poultry or meat cuts; spraying at high pressures may not achieve the desired high temperatures and may generate condensate, but it may also accomplish removal of visible soil; low pressures yield higher tissue temperatures, while flooding with hot water should achieve high temperatures on and throughout irregularly shaped carcasses or cuts (Sofos and Smith, 1998a). Hot water is approved for carcass decontamination in the United States, and effective temperatures exceed 74°C, becoming more effective as they approach 80-85°C. The routine use of hot water in commercial applications will depend on its availability, the need for decontamination by individual plants, and its effect on product decontamination as well as product quality/appearance in specific operations (Sofos, 1998a; Sofos and Smith, 1998a).

Another form of thermal decontamination involves exposure of carcasses to pressurized steam (Davidson et al., 1985; Morgan et al., 1996; Nutsch et al., 1997, 1998; Phebus et al., 1997) and a patented process (the Frigoscandia SPS®) has been approved and used in the United States. Commercially, "steam pasteurization" is applied for approximately 6 sec to avoid carcass discoloration concerns, and reduces bacterial counts by 1-2 logs (Gill, 1998). Reported advantages of exposure to pressurized steam, over spray-washing

applications, include reduced water and energy usage. However, "steam pasteurization" requires a major capital investment and is applied after washing of carcass sides. Nevertheless, "steam pasteurization" can be an additional intervention that further reduces carcass contamination before chilling. The impact of decontamination interventions, such as "steam pasteurization," on the microbiological quality of carcasses will depend on extent of continuous equipment use, proper operation, and extent of potential re-contamination of meat during subsequent stages of handling (Sofos and Smith, 1998a). Gill (1999) cautions that, because pasteurizing treatments will inevitably cause some degradation of carcass appearance, there could be a tendency for plant personnel to reduce the time or temperature to minimize damage to carcasses which could be carried so far as to render the treatment ineffective.

Other technologies: A variety of other processes, including ionizing radiation, hydrostatic pressure, electric fields, pulsed light, sonication and microwaves have been proposed for application to reduce contamination in meat (Bawcom et al., 1995; CAST, 1996; Bolder, 1997; Dunn et al., 1995; Farkas, 1998; Hoover, 1993, 1997; Lillard, 1994). Ionizing radiation has been approved for decontamination of fresh meat and poultry in the United States, but its commercial use is limited at the present time.

Decontamination with multiple processes: Use of two, three or more processes may yield synergistic or additive decontaminating effects (Sofos, 1998a; Sofos and Smith, 1998a), and could be considered as a "multiple hurdle" (Leistner, 1995) decontamination approach. The higher the initial contamination, the greater the decontaminating effect of single or multiple sequential decontamination technologies (Castillo et al., 1998b, 1999; Dorsa et al., 1996, 1997a; Graves Delmore et al., 1998). Increased water temperatures (50-55°C) enhance the effect of acid solutions (Cutter et al., 1997). Graves Delmore et al. (1998) reported reductions in *E. coli* counts on beef adipose tissue samples of up to 4.3 log cfu/cm^2 by use of pre-evisceration washing, followed by acetic acid solution rinsing, followed by warm-water washing and terminating in final carcass washing with an acetic acid solution rinse. Application of lactic acid rinse, following hot water washing, was more effective than their use in the opposite order (Castillo et al., 1998b). The multiple intervention decontamination approach is used in operations to help them meet the performance criteria set in the United States meat and poultry inspection regulations, or when their customers demand application of such technologies (Sofos and Smith, 1998a). We have evaluated (Bacon et al., 1998) the concept of multi-intervention decontamination as applied in 8 commercial plants and verified its effectiveness in reducing bacterial counts and incidence of *Salmonella*. Overall average initial carcass total plate counts, coliform counts and *E. coli* counts of 7.6, 4.6 and 4.1 log CFU/100 cm^2 were reduced to 3.3, 1.0 and 0.9 log CFU/100 cm^2 after chilling, respectively. Overall incidence of *Salmonella* was reduced from the 14.7% to 1.9%.

Edible offal decontamination: Delmore (1998), in our laboratory, evaluated processes, such as solutions of chlorine (0.005%), acetic acid (2%) lactic acid (2%) or trisodium phosphate (12%), hot water (78-80°C), and steam, applied by immersion, spraying or diffusion, for the decontamination of cheek meat, large intestine, lips, liver, oxtail and tongue. Chlorine and steam were among the least effective, while the acids and hot water were among the most effective decontamination interventions. Depending on product, average reduction in aerobic plate counts achieved with chlorine, acetic acid, lactic acid, trisodium phosphate, hot water and steam were in the ranges 0.1-0.6, 0.3-2.6, 04-1.7, 0.5-1.2 and 0.0-2.0 log CFU/g, respectively. Depending on decontamination treatment, reductions in aerobic plate counts achieved in cheek meat, large intestine, lips, liver, oxtail and tongue were in the ranges 0.3-1.1, 0.2-1.0, 0.0-1.8, 0.1-1.0, 0.1-1.5 and 0.4-2.6 log CFU/g, respectively. Additional experiments with acetic and lactic acid, applied by immersion (2%, 50°C, 5 or 10 sec) were effective in reducing *L. monocytogenes* and *E. coli* O157:H7 inoculated on samples of the same products (Delmore, 1998). The results indicated that *E. coli* O157:H7 was more resistant to decontamination than *L. monocytogenes*, and that the most effective treatment was exposure to lactic acid for 10 sec. In another study (Zerby et al., 1998b) we evaluated decontamination of pork variety meats (cheek meat, salivary gland, tongue, liver, heart, stomach and chitterlings) with chlorine, acetic acid, lactic acid, trisodium phosphate, acidified sodium chlorite, hot water and steam. Acetic acid, lactic acid and trisodium phosphate were the most effective decontamination treatments for pork variety meats, with lactic acid immersion being the best. The results indicated that exposure of beef and pork variety meats to decontamination treatments also resulted in sublethal injury of a portion of the bacterial contamination (Delmore, 1998; Zerby et al., 1998b). Injured bacterial cells may repair their injury and cause concerns during extended product storage. In general, these studies have shown that processes applied to carcasses can also be considered for decontamination of edible offal. Decontamination interventions, however, need to be applied in conjunction with good manufacturing practices in the spirit of the principles of HACCP in order to enhance the microbiological quality of any product, including variety meats.

Microbiological performance criteria: As indicated, the United States regulations have set microbiological performance criteria for meat and poultry that need to be met in plants operating under the principles of HACCP (FSIS, 1996). These criteria include sampling of 24-hour chilled carcasses (1 out of every 300 for large beef plants) and enumerating *E. coli* from three carcasses sites (brisket, flank, rump) (100 cm^2 each) combined. The same sampling protocol, or sampling of ground beef when produced, is applied by FSIS inspectors and these samples are analyzed for presence of *Salmonella*. The regulation has set limits in *E. coli* counts or *Salmonella* incidence that, if exceeded, indicate process failure, and the need for improvements in the process to meet the criteria. In a major study in 4 steer/heifer and 3 cow/bull slaughtering plants, we collected carcass samples, by excision, from the above mentioned carcass sites, at pre-evisceration, after final carcass washing and after 24 hours of carcass chilling, during two seasons (November-January and May-June) and analyzed them for *E. coli* and *Salmonella*. The data were analyzed statistically to determine probabilities of passing the regulatory performance criteria (FSIS, 1996). The results obtained before and after carcass washing indicated that decontamination processes (which varied among plants) had a major influence in reducing levels of contamination and increasing probabilities of passing the performance criteria (Sofos et al., 1999b,c). Probabilities of passing the *E. coli* performance criteria, depending on individual plants, anatomical carcass site, season and type of animal slaughtered, ranged between 0.0 and 1.0 at

pre-evisceration and between 0.654 and 1.0 after carcass washing, but before chilling (Sofos et al., 1999b). After a 24-hour carcass chilling period, the probabilities of passing for steer and heifer carcasses were in the ranges of 0.597-1.0, 0.641-1.0 and 0.71-1.0 for the brisket, flank and rump, respectively; the corresponding probabilities for cow and bull carcasses were 0.966-1.0, 0.471-1.0 and 0.485-1.0 (Sofos et al., 1999b). Probabilities of passing the regulatory criteria (FSIS, 1996) for *Salmonella* contamination, for all carcass sites combined, were 0-1.0 at pre-evisceration, and 0.242-1.0 after carcass washing for steers and heifers; the corresponding values for cows and bulls were 0.004-0.974 and 0.245-1.0, respectively. After carcass chilling, the point at which the regulation requires testing, the probabilities of passing for steer and heifer carcasses were 0.242-1.0 and 0.722-1.0 during November-January and May-June, respectively; the corresponding probabilities for cow and bull carcasses were 0.368-0.974 and 0.865-1.0 (Sofos et al., 1999c). Total bacterial, coliform and *E. coli* counts were correlated significantly with incidence of *Salmonella* only for samples from cow and bull carcasses that had a higher incidence of the pathogen than steer and heifer carcasses. The results of these studies have demonstrated in commercial practice the major influence of a variety of decontaminating processes, described in this paper, in reducing levels of contamination. The results also indicate the need for individual plants to examine their operations and to establish sanitation, hygiene and good manufacturing practices that will assist them in the improvement of the microbial quality of raw beef.

Safety and meat quality: Application of decontaminating processes may have an influence on product and worker safety and product quality, and, therefore, these criteria should be considered in treatment selection. Acceptable decontaminating processes should not have adverse toxicological or other health, effects on workers during their application or on consumers as a result of their use. Decontamination technologies based on heat are not associated with potential health concerns or with product safety, provided that the water meets drinking standards. Use of chemical solutions, however, depends on their toxicological properties, as well as on their effects on product quality and acceptability, and on the potential for environmental pollution problems associated with their use. Application of any decontamination technology should be in compliance with worker safety guidelines. Potentially undesirable effects of thermal and chemical decontaminating processes may be associated with color/appearance and flavor/odor changes. Therefore, their concentration, intensity and length of application should be selected based on antimicrobial as well as quality criteria (Gill and Badoni, 1997; Smulders and Greer, 1998; Sofos and Smith, 1998a).

Even if spray-washing or other types of decontaminating technologies are effective on carcasses, the microbial status of the resulting meat will be affected by subsequent handling, exposure to additional contamination, and application of further decontamination or preservation treatments. It is logical to expect however, that carcass decontamination, if proper and effective, should reduce incidence of pathogens of fecal origin that are mostly introduced in the plant, and originating on or in the animals. Carcass decontamination coupled with proper subsequent sanitation and handling of the resulting meat, should reduce levels of pathogens that need to be controlled or inactivated before consumption (Sofos and Smith, 1998a).

Carcass cooling

Carcasses may be exposed to additional contamination and microbiological proliferation during chilling or cooling, which follows slaughter, dressing and decontamination. These problems can be minimized by sanitary and hygienic practices and facilities, and proper chilling of carcasses to temperatures that do not allow, or greatly reduce, microbial growth (Schmidt et al., 1998). Rapid pre-rigor chilling may be undesirable in beef and lamb carcasses due to potential loss of tenderness (Tornberg, 1996), but muscle toughening can be avoided by application of electrical stimulation or very rapid chilling procedures (Joseph, 1996). In most practical situations, commercial chilling of beef carcass sides to temperatures below 7 °C requires 18-36 hours. This chilling rate may be adequate considering that the internal muscle tissues should be essentially sterile (Gill, 1998). In addition to temperature, microbial growth on carcass surfaces may also depend on presence of moisture available for microbial growth as well as other factors (Gill and Jones, 1997). Dry carcass surfaces may lead to decreases in microbial counts when combined with cold temperatures, but inactivation of bacteria is generally more difficult in the dry condition. Drying of carcasses during chilling results in weight losses and a large number of operations in the United States apply intermittent spraying of carcasses with chilled water, especially during the initial stages of chilling, to facilitate carcass temperature decreases without loss of surface moisture (Gill, 1998). However, additional studies are needed to optimize chilling processes and to control microbial contamination (Greer at al., 1990; Jericho et al., 1998; Strydom and Buys, 1995). Carcass cooling should be uniformly rapid to avoid hot spots of bacterial multiplication and subsequent redistribution of bacteria during fabrication, as well as cross-contaminating additional product. Requirements for adequately low, deep muscle temperatures before fabrication are also necessary to avoid microbial proliferation during and following fabrication, especially in the center of boxed product, of trimmings in large combo bins, or at the center of boxes in storage or during transportation.

Fabrication and storage

Carcass chilling is usually followed by fabrication into primal and subprimal cuts, and trimmings, which are packaged in pouches or bags, placed in boxes or in combo bins, and shipped elsewhere for further fabrication or processing before retailing. These processes should also be performed in sanitary and hygienic environments and equipment, under good manufacturing practice principles. All the gains in reduction of contamination achieved by decontaminating processes during slaughter, dressing and chilling may be compromised during fresh meat fabrication, handling and distribution. Proper plant and equipment cleaning and sanitation practices to eliminate organic matter residues, microbial contamination and biofilm formation, as well as personnel training in hygienic practices are important prerequisites, along with appropriately chilled carcasses, properly cooled fabrication environment, and rapid product throughput to avoid contamination problems during fabrication. Fresh meat should be stored at low temperatures to prevent or reduce microbial growth. Temperatures below 5-7 °C inhibit growth of mesophilic microorganisms, while psychrotrophs may grow, but at a reduced rate. Frozen storage below -5 to -10 °C will inhibit growth of all microorganisms of concern in foods.

Another important consideration is whether carcass decontamination has any lasting effect on the microbial quality of the resulting meat (Sofos and Smith, 1998a). This is difficult to evaluate since contamination and conditions during subsequent handling and distribution are also influential and variable among operations, but several studies have indicated that decontamination with organic acids may have a better residual antimicrobial effect during product storage than other decontaminating processes (Dorsa et al., 1997b, 1998a,b; Gorman et al., 1997). Additional studies are needed to evaluate the effect of the newer carcass decontamination processes on subsequent product quality, as well as to evaluate effects on quality engendered by the application of decontamination technologies to meat cuts. Exposure to additional contamination during carcass cutting probably negates benefits of carcass decontaminating treatments relative to spoilage microorganisms. A benefit of all carcass decontamination treatments could be that, if effective, they should reduce the incidence of fecal pathogens on the carcass. If no fecal contamination is present during subsequent cutting of the carcass, then the meat should have lower incidence of pathogens of fecal origin (Sofos and Smith, 1998a).

Conclusions

Increased consumer concern about food safety has led to establishment of new meat and poultry inspection regulations in the United States, which require operation under HACCP protocols/systems and testing of meat to determine whether established microbiological criteria or standards are met. These developments have led to intensified research, development and application of meat decontamination technologies with the objective of helping the industry to meet the regulatory requirements, and, to provide the consuming public with a microbiologically cleaner and safer product. Decontamination technologies applied, or considered, include animal cleaning, chemical dehairing, knife-trimming, steam-vacuuming, carcass washing, spraying, or rinsing with water of low or high temperatures/pressures, or with chemical solutions such as chlorine, organic acids, and trisodium phosphate, application of pressurized steam following carcass washing, or use of multiple decontamination treatments in sequence. Selection of decontamination technologies by individual companies may depend on cost, need for decontamination, facilities available, availability of other resources (e.g., hot water, steam, plant design), and product destination since some countries do not allow application of carcass decontamination interventions. Application and management of decontamination processes, described in this paper, under the principles and spirit of HACCP and improvements in overall hygiene, sanitation and good manufacturing practices should reduce pathogen incidence and enhance product quality. Continuous improvement and enhancement of the HACCP program and its application throughout the chain, from production to consumption, should lead us to a safer meat supply. The extent of carcass contamination before as well as after application of single or multihurdle decontamination treatments can be influenced by facility design, sanitation and hygiene, and good manufacturing practices, which can also influence the efficacy of decontamination. Without the foundation of good plant design, proper sanitation, hygiene and good manufacturing practices, even the best decontamination technologies will fail. Decontamination technologies should not be used to correct problems that can be prevented or avoided through proper design, sanitation, operation, and, generally, good manufacturing practices, or to allow plant operation at high speed. However, decontamination treatments can prove useful in reducing accidental/unnoticed contamination, especially of fecal origin, that may contain pathogens. Appropriate implementation of decontamination technologies and strategies should lead to consistently cleaner carcasses with minimal contamination of fecal origin. The microbiological status of the product that reaches the consumer, however, either as raw meat or processed products, will also depend on exposure to contamination and its control during subsequent chilling, fabrication, processing, handling, distribution and preparation for consumption. Proper application of decontamination processes will yield a product that should be safe for consumption following adequate cooking.

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