Beef Decontamination Technologies

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Introduction

Beef carcasses, which are initially sterile, become contaminated with bacterial pathogens via transmission of organisms from the exterior of the live animal, and/or from the environment, to the product surface. Extensive contamination, or abusive conditions that allow bacteria to reproduce, increase risk for presence of pathogenic bacteria and formation of toxins in food (Sofos *et al.*, 1999). Highly publicized outbreaks of foodborne disease since 1993, primarily caused by bacteria such as *Escherichia coli* 0157:H7 and *Listeria monocytogenes*, elicited intense consumer concern about meat safety. In response, regulatory authorities, researchers, and the beef industry-initiated efforts to implement food safety management systems to improve microbiological quality.

To improve beef safety, the USDA Food Safety and Inspection Service (FSIS) began initiating new regulatory requirements during the mid-1990s. Packers now must knife-trim carcasses to remove all visible contaminants, must comply with written sanitation standard operating procedures (SSOP), must have implemented hazard analysis critical control point (HACCP) systems, and must meet microbiological performance criteria and standards for *Escherichia coli* and *Salmonella* as a means to verify HACCP effectiveness and pathogen reduction. Researchers and beef packers/processors addressed consumer food safety concerns by developing a variety of methods that are now implemented, or are being further developed, to reduce numbers of bacteria on beef and improve microbiological safety (Sofos *et al.*, 1999). These microbiological decontamination technologies include animal cleaning, chemical dehairing at slaughter, spot-cleaning of carcasses by knife-trimming or steam/hot- water vacuuming, and spraying/washing/rinsing of carcasses before evisceration and/or before chilling, with water, chemical solutions and/or steam or hot water. Research has demonstrated that such decontamination technologies are most effective when used in combination, sequentially, as "multiple hurdles" systems. Such systems improve regulatory compliance and enhance product safety (provided that processing and preparation for consumption also are performed using good hygiene practices) and are the topic in injured bacteria, which may be of concern during subsequent product storage if they repair their injury, or could be advantageous if subsequent decontamination treatments or chilling result in further bacteria death.

Overall, the bacterial quality of dehaired carcasses should be improved in facilities designed to process dehaired cattle. Removal of dirt, feces, and hair in a separate room and before hide removal should decrease the risk of transferring pathogens to surfaces of beef carcasses. However, carcass contamination also depends on plant design, good processing, sanitation and hygienic practices, and overall avoidance of environmental cross-contamination here.

Decontamination Technologies

The extent to which beef carcasses are contaminated with bacteria is influenced mostly by variation among plants, including plant design, speed of slaughter and skill of operators; but also varies with season of the year, type of animal slaughtered, anatomical carcass site, and step in the dressing process (Sofos *et al.*, 1999). Efficacy of methods used to reduce numbers of bacteria on the surface of carcasses is influenced by water pressure, temperature, chemicals present and their concentration, time of exposure (which depends on chain speeds and length of the application chamber), method of application, chamber design, and time or stage of application. Application of decontamination processes may have an influence on product and worker safety and product quality, as well as on the environment, and, therefore, these criteria should be considered in treatment selection. Acceptable decontamination systems should not have adverse toxicological or other health effects on workers during their application, or on consumers as a result of their use (Sofos *et al.*, 1999).

Even if beef carcass decontamination technologies are effective, the microbiological status of resulting product will be affected by subsequent handling, exposure to additional contamination, and application of further decontamination or preservation treatments. Nonetheless, carcass decontamination should reduce incidence of pathogens of fecal origin that are mostly introduced in the plant and originating on or in cattle. Following are descriptions of methods that are currently used, or that are being developed for use, to reduce bacterial contamination on beef.

Chemical dehairing: A patented process (Bowling and Clayton, 1992) for chemically dehairing cattle early during the harvest process is now being used commercially to remove hair, mud, manure and other external contaminants from cattle before hides are removed.

The process was applied experimentally in a commercial beef slaughtering operation and the bacteria counts on resulting carcasses were compared with those from cattle that were not subjected to chemical dehairing (Schnell *et al.*, 1995). Chemical dehairing reduced visible contaminants on carcasses and the amount of knife-trimming needed to comply with regulatory requirements. Application of the dehairing process to hide samples in additional laboratory experiments caused significant reductions in numbers of inoculated *E. coli* 0157:H7, *Salmonella* spp. and *L. monocytogenes* present (Castillo *et al*., 1998; Graves Delmore *et al.*, 1997b). Graves Delmore *et al.* (1997b) suggested that chemical dehairing results in injured bacteria, which may be of concern during subsequent product storage if they repair their injury or could be advantageous if subsequent decontamination treatments or chilling result in further bacteria death. Overall, the bacterial quality of dehaired carcasses should be improved in facilities designed to process dehaired cattle. Removal of dirt, feces, and hair in a separate room and before hide removal should decrease the risk of transferring pathogens to surfaces of beef carcasses. However, carcass contamination also depends on plant design, good processing, sanitation and hygienic practices, and overall avoidance of environmental cross-contamination.

Spot carcass decontamination: Beef harvesting in modern, high-speed packing plants consists of a sequence of more than thirty operations, often involving hundreds of workers. Some operations, especially those associated with removal of the hide, result in

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external contamination of carcasses and of the plant, and in cross-contamination and redistribution of bacteria from heavily contaminated to cleaner parts of the carcass. Although some studies have questioned the effectiveness of mandating carcass trimming as a decontamination method (Gill et al., 1996), knives are routinely used to remove visible contamination during dressing; this is required by FSIS "zero tolerance" performance standards. As an alternative, FSIS approved use of hand-held steam vacuums (for spots <2.5 cm in diameter) to remove visible contamination on beef carcasses. Steam vacuuming uses steam and/or hot water to loosen soil and kill bacteria, followed by application of a vacuum to remove contaminants (Castillo et al., 1999a; Dorsa et al., 1996; Kochevar et al., 1997; Sofos et al., 1999), much like a household steam carpet cleaner. This technology is now applied extensively by beef packers because it reduces the need for carcass knife-trimming.

Visible contaminants and bacterial counts have been reduced using commercial steam vacuuming systems to at least those levels achieved by knife- trimming (Dorsa et al., 1996; Kochevar et al., 1997). Effectiveness of steam vacuuming depends upon 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 are applied only to specific areas of a carcass-generally those areas known to be heavily contaminated (Sofos and Smith, 1998).

Chemical decontamination: Most commercial beef packing plants apply chemical decontaminates via spray rinsing cabinets through which carcasses are passed automatically. Today, decontamination systems using chemical agents are approved by FSIS for use as a component of a HACCP Plan if the chemicals (a) are "Generally Recognized as Safe" (GRAS) by the Food and Drug Administration, (b) do not create an "adulterant" situation, (c) do not create labeling (i.e., "added ingredients") issues, and (d) can be supported with scientific studies as being effective.

The most frequently used chemical decontaminants are solutions of organic acids (1-3%), such as acetic and lactic acids, which reduce numbers of bacteria on carcass tissue (Smulders et al., 1986; Sofos et al., 1999). Such organic acids are most useful as warm (50-55 oC) rinses, applied before chilling, especially in combination with preceding treatment using hot water or steam (Gorman et al., 1997; Hardin et al., 1995). Potential concerns associated with use of organic acids include selection for presence of acid- resistant bacteria that may accelerate rates of product spoilage, increase undesirable effects on product appearance, and speed equipment corrosion (Gill, 1998).

In addition to organic acids, several other chemical solutions have been proposed and tested (some have been approved) for use in decontamination systems. Such chemicals 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, and activated lactoferrin.

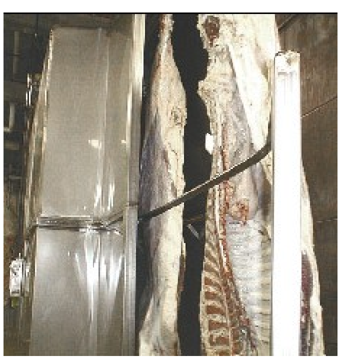
Trisodium phosphate solutions are approved for treatment of beef carcasses (Bender and Brotsky, 1992; Dickson et al., 1994). Research by Cabedo et al. (1996) and Gorman et al. (1995; 1997) showed that spray- washing with trisodium phosphate reduced contamination of beef brisket, and that it may inhibit bacterial attachment, thereby allowing easier bacterial cell removal by washing (Cabedo, 1995). Hydrogen peroxide and ozonated water are approved for use and have been found to reduce bacteria counts (Cabedo et al., 1996; Gorman et al., 1995; Reagan et al., 1996), but use of these chemicals may elicit oxidation (increased rancidity) of fat and muscle pigments.

Research by Cutter et al. (2000) showed that spray-washing of beef fat with a solution of cetylpyridinium chloride (1%) immediately reduced inoculum levels (100,000 to 1,000,000 colony forming units) of Escherichia coli 0157:H7 and *Salmonella* Typhimurium to virtually undetectable levels. A similar study by Ransom et al. (2001) generated similar conclusions. However, residual cetylpyridinium chloride levels following treatment were considered excessive for human consumption, and this chemical has yet to receive federal approval for use.

Spraying of beef carcasses with room-temperature acidified (citric acid-activated) sodium chlorite-SanovaM, marketed by the Alcide Corporation (Redmond, WA)-has been shown to substantially reduce numbers of inoculated E. coli 0157:H7 (Castillo et al., 1999b). Acidified sodium chlorite also effectively reduced, to levels close to or below the counting method detection limit, pathogens that were spread to areas beyond the initially contaminated area. However, 22% to 50% of carcasses treated with acidified sodium chlorite still yield countable *E. coli* 0157:H7 colonies. This chemical recently received approval from the federal government for use in beef carcass decontamination systems.

Recent work by Naidu (2000) suggests that use of "activated lactoferrin" can provide an additional mechanism for reducing the incidence of meatborne pathogens on beef. Activation (by gastric pepsin cleavage) of bovine lactoferrin, which is readily available as a product of the dairy industry, yields a potent bactericidal peptide (lactoferrin B) that inhibits and/or inactivates a physiologically diverse range of pathogens, including *Escherichia coli*, *Salmonella* Enteritidis and *Listeria monocytogenes*. The effective dose (Bellamy et al., 1992) of lactoferricin B that will kill most pathogens is 10 mg/ml.

Little is presently known about peroxyacetic acid. Reportedly (InfoMeat, 2000), in a partnership with CHAD, Inc. (Olathe, KS), the Ecolab Company (St. Paul, MN) created a new antimicrobial agent designed for pre- chilling application to carcasses, which is marketed as Inspexx 200TM. A mixture of hydrogen peroxide, acetic acid, octanoic acid and other chemicals, the solution was approved for use in 2000. A study by Ransom et al. (2001) found that pure solutions of peroxyacetic acid were moderately effective in reducing numbers of bacteria on beef surfaces, but slightly less effective than using lactic acid.



With the availability now of many different chemical agents that may be used in decontamination systems, it may be prudent to rotate use of differing agents over time within a plant to prevent development of acid-shocked or acid-resistant strains of pathogens (Samelis *et al*., 2001). Periodic rotation of chemical agents (including sanitizers) may help to prevent selection for bacterial resistance to singular treatments, thereby preventing further transmission of such organisms downstream in the marketing chain.

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Thermal decontamination: Treatment with hot water (Davey and Smith, 1989) is approved for carcass decontamination. Effective water temperatures exceed 74°C, and effectiveness increases as temperatures approach 80-85°C. Reagan *et al.* (1996) found that hot water spray-washing of beef reduced bacterial counts and achieved more consistent decontamination compared to knife- trimming. Graves Delmore *et al.* (1997a) found that hot water rinsing, in addition to removing visible soil, also reduced coliform counts. Cabedo *et al.* (1996) found that, even after exposure to contamination for 2 or 4 hours, hot water (74°C) was more effective than other treatments at reducing numbers of bacteria present.

In practice, beef carcasses are decontaminated with hot water via spray washing cabinets (much larger volumes of water are used than in chemical rinsing systems) through which carcasses are passed automatically. Spraying at high pressures requires very high water temperature at the nozzle because water temperature is reduced quickly as it is sprayed from a nozzle to the carcass surface; low pressures yield higher tissue temperatures (Sofos and Smith, 1998). Hot water can be problematic as it may generate condensate; nonetheless, high pressure and large volumes of hot water can remove visible soil in addition to reducing microbial counts.

Another thermal decontamination technique is exposure of carcasses to pressurized steam (Davidson et al., 1985; Nutsch et al., 1998; Phebus et al., 1997); a patented commercial process (the Frigoscandia SPS®) is currently approved and used by several packers. Commercially, "steam pasteurization" reduces bacterial counts by applying pressurized steam to the surface of carcasses for about 6 sec; longer exposure periods may cause discoloration. Reported advantages of using pressurized steam over spray-washing applications include reduced water and energy requirements. However, "steam pasteurization" requires a major capital investment and is applied after washing of carcass sides. Gill (1999) cautioned that, because steam pasteurization will degrade carcass appearance, there could be a tendency for plant personnel to reduce application times or temperatures to minimize carcass damage, and that such reduction 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 (Lillard, 1994; Bawcom et al., 1995; Dunn et al., 1995; CAST, 1996; Bolder, 1997; Hoover, 1997; Farkas, 1998; Sofos et al., 1999). Ionizing radiation has been approved for decontamination; commercial use of radiation (electronic pasteurization) should continue to grow. Although considered to be a "kill step" in meat processing, ionizing radiation should not be construed by consumers to impart "zero risk" of pathogen contamination to product; appropriate handling and hygiene remain very important to prevention of food borne illness.

Decontamination of beef variety meats: Experiments conducted by Delmore (1998) evaluated effectiveness of decontaminating six beef variety meats with solutions of chlorine, acetic acid, lactic acid or trisodium phosphate, hot water (78-80°C), and steam, applied by immersion, spraying or diffusion. Chlorine and steam were among the least effective, while application of acids and hot water were among the most effective decontamination treatments. Immersion of beef variety meats in acetic and lactic acid were effective in reducing inoculated L. monocytogenes and *E. coli* 0157:H7 on samples of the same products, and *E. coli* 0157:H7 appeared more resistant to decontamination than *L. monocytogenes*. Exposure of beef variety meats to decontamination treatments also resulted in sublethal injury of some bacteria. Injured bacterial cells may repair their injury and cause concerns during extended product storage. In general, processes applied to carcasses also can be considered for decontamination of edible offal.

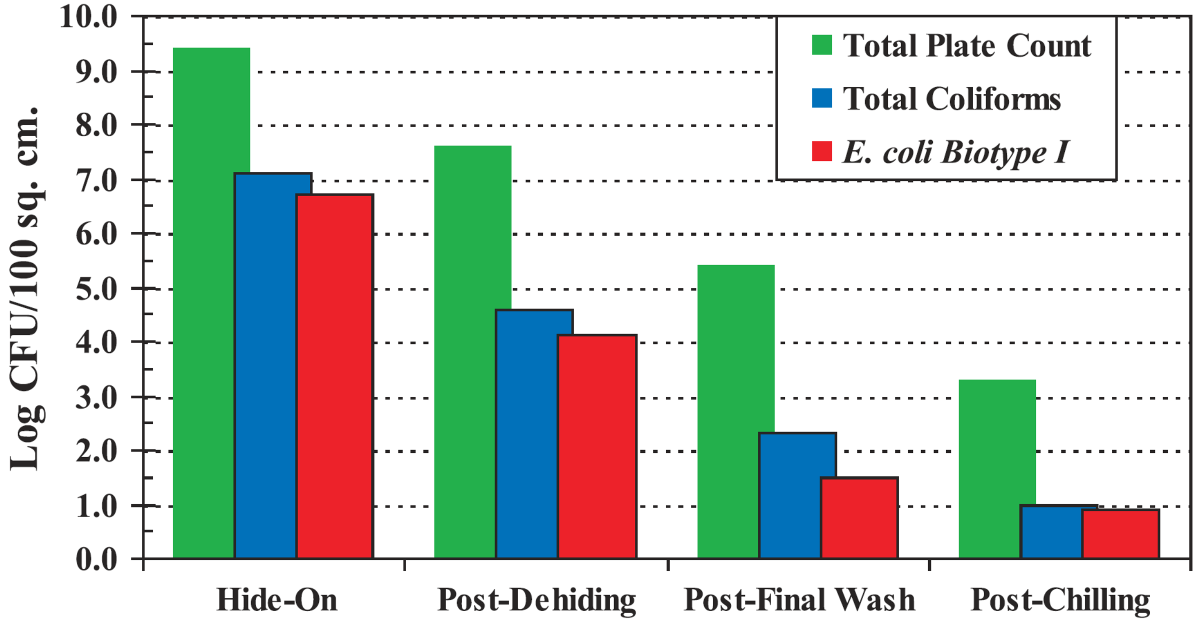
Using 'Multiple Hurdles 11: Synergistic or additive effects are obtained when combinations of two or more decontamination systems are used in sequence. Together, such an approach is referred to as a "multiple hurdles" (Leistner, 1995) system. The more initial contamination, the greater the decontaminating effect of multiple hurdles technologies. Graves Delmore et al. (1998) reported laboratory reductions in *E. coli* counts on beef fat when pre-evisceration washing, followed by acetic acid solution rinsing, followed by warm-water washing and terminal final washing with an acetic acid solution rinse were used. Bacon et al. (2000a) evaluated commercial multiple hurdles systems as applied in eight commercial beef packing plants (Fig. 1). Decontamination treatments in that study included steam-vacuuming, pre-evisceration washing with organic acid application, zero-tolerance compliance, hot-water pasteurization, a second application of organic acid rinse, and final washing. The study verified effectiveness of the multiple hurdles systems by demonstrating substantial reductions in bacterial counts and incidence of *Salmonella* presence. *Salmonella* on carcasses was reduced from 14.7% to 1.9%. Bacon et al. (2000b) evaluated data provided by 12 commercial packing plants and reported that incidence of *E. coli* 0157:H7 was 3.6%, 0.4% and 0.0% for samples collected from beef hides, from carcass sides prior to washing, and from carcass sides following final decontamination, respectively. It now seems apparent that addition of appropriate and sequential carcass decontamination technologies in beef plants reduces the risk of pathogens being transmitted from cattle to consumers.

Summary

Beef decontamination technologies include chemical dehairing, knife-trimming, steam-vacuuming, carcass washing, spraying, or rinsing with chemical solutions such as organic acids, or with water of low or high temperatures/pressures, application of pressurized steam following carcass washing, or use of multiple decontamination treatments in sequence.

Decontamination treatments can prove useful in reducing accidental/unnoticed contamination, especially of fecal origin and that may contain pathogens, provided that processing and preparation for consumption also are performed properly using good hygiene practices. Appropriate implementation of decontamination technologies and strategies should lead to consistently cleaner carcasses with minimal contamination of fecal origin, and product that should be safe for consumption following adequate cooking.

Figure 1. Microbiological effectiveness of "multiple hurdles" technology, by stage of the harvesting process, in eight commercial beef packing plants (source: Bacon *et al.*, 2000a).



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