Microbiological Decontamination of Food Animal Carcasses by Washing and Sanitizing Systems: A Review

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ABSTRACT

Microbial contamination of animal carcasses is a result of the necessary procedures required to process live animals into retail meat. The contamination can be minimized by good manufacturing processes, but the total elimination of foodborne pathogenic microorganisms is difficult, if not impossible. A variety of methods have been developed to reduce the levels of contaminating bacteria on carcasses, although most of the current methods focus on washing and sanitizing procedures. The commonly used sanitizing agents include hot water, chlorine, and short-chain organic acids. The effectiveness of these compounds varies by the concentration used, the temperature of the sanitizers and contact time, the sensitivity of the native microflora to the specific compound, and to a certain extent the design of the specific experiments. The consensus of the research is that carcass sanitizing can reduce the initial levels of bacteria on the surface of the carcass.

Contamination of animal carcasses during slaughtering procedures is undesirable but unavoidable in the conversion of live animals to meat for consumption. Internal carcass surfaces are essentially sterile, and most initial contamination of red meat carcasses is contributed by the hide during removal (51,64-66). The exposed surface of the hide and the hair accumulate dust, dirt, and fecal material, and this is the primary source of bacterial contamination during slaughter (17,118). The factors that affect the extent of this contamination have been reviewed by Patterson (105) and Grau et al. (69). Much of the microflora transferred to the tissue surfaces, while aesthetically undesirable, is nonpathogenic. However, pathogens such as Salmonella (31), Campylobacter (21), and Listeria (29) can be present.

CARCASS CONTAMINATION

Animals carry a large and varied microflora when they arrive at the abattoir, both in their intestinal tracts and on their hide and hooves (68). The nature of this microflora will vary among individual animals, different herds, and seasons of the year (49,71,73). Gill and Newton (62) and McMeekin (97) have reviewed the literature concerning total bacterial populations of carcasses and retail cuts and reported that some bacteria on meat may come from diseased animals which had bacterial populations around the lymph nodes. However, the authors noted that the significant portion of the microflora was confined to the surfaces of the carcass after slaughter and that the most likely sources of this contamination were dirt and fecal material on the hide and dirty processing equipment. In a review of intrinsic bacteria in meat, Gill (60) noted that clostridia may occasionally be found in small numbers in the deep muscle tissue of apparently healthy animals.

Mackey and Derrick (94) demonstrated that slaughter instruments could spread contamination into the internal organs of beef cattle, by contaminating a captive bolt pistol and stick knives with marker bacteria and then examining the tissue for these specific organisms. The workers in slaughter operations can also be a source of contamination, as Salmonella spp. and Escherichia coli have been isolated from the hands of workers even after thorough washing (37,38). However, automation of a beef slaughtering operation did not significantly alter the total bacterial populations on the carcasses, although there was a significant shift in the levels of contamination between sites on a carcass (134). Several researchers have reported contamination of carcasses can be minimized by good sanitation practices (24,47,61) or "strict hygiene" (122) during slaughter procedures.

Carpenter et al. (23) found that there was considerable variation in microbial levels from hogs slaughtered at different abattoirs. The authors noted that the area of the skin side of the ham, near the anal opening, was the most frequent site of Salmonella isolation. Other observations in hog slaughtering operations reported that fecal contamin-
tion of carcasses was as high as 66% (93). A survey of slaughter operations in Norway showed that the brisket, forerib, flank groin, and round sites on beef carcasses consistently had higher total bacterial counts than other sites sampled on the carcass (76). The same researchers also found that the most contaminated areas of pork carcasses were the cheek and abdominal lateral surface (belly). Ingram and Roberts (75) have discussed the difficulties in obtaining valid microbiological data from carcasses because of the large variations in microbial contamination between carcasses and sample sites on individual carcasses. Roberts (113) also noted that, because of these variations, changes in procedures or facilities based on preconceived ideas might not achieve the desired results. Roberts et al. (114) noted that several sites on a carcass should be sampled to determine the true nature of bacterial contamination.

Bacterial attachment is presumed to be the first step in the contamination of solid surfaces. Attachment is generally considered to be a two-step process, consisting of an initial, reversible attachment to the surface followed by a more permanent, irreversible attachment (95). Firstenberg-Eden (56) reviewed the early literature on the attachment of bacterial cells to meat and concluded that during the initial stage, attachment was regulated by physical forces, and the secondary stage was regulated by bacterial production of extracellular polysaccharides. Notermans and Kampelmacher (101) reported an increase in numbers of attached cells to chicken skin as immersion times increased. These researchers, and later Farber and Idziak (55), reported that motile cells attached more readily to chicken skin or beef than nonmotile cells. However, McMeekin and Thomas (98) and Lillard (88) could not confirm these findings. Firstenberg-Eden et al. (57) expressed bacteria attached to both chicken and beef in terms of an "S value," which was intended to differentiate between bacterial cells which were firmly attached to the tissue surface and those which were simply trapped in a moisture layer on the surface. This S value was later used, with some modifications, by Butler et al. (22), Farber and Idziak (55), and Dickson and Koohmaraie (45) as an indication of the portion of the total bacterial population in association with a tissue surface which was in fact "attached" to that surface.

Previously cited reports determined bacterial populations by conventional culture techniques, i.e., plate counts. However, several researchers have used electron microscopy for both qualitative and quantitative evaluations of attached bacteria. Butler et al. (22) observed attached bacterial cells on pork skin subjected to various processing techniques and reported that extracellular material did not appear to be involved in attachment and microcolony formation until 12-24 h after the initial cell contact with the tissue. Schwach and Zottola (116) noted that attachment of bacterial cells to beef tissue was probably a result of physical attachment of the cells to the tissue and entrapment of the cells by beef tissue fibrils. Benedict et al. (19) reported that bacteria attach to connective tissue fibers, rather than myofibrils, and that processing could cause swelling of these fibers and result in entrapment of individual cells.

Thomas and McMeekin (128) attempted to quantify numbers of attached cells by scanning electron microscopy (SEM), and reported that the presence of low levels of salt in the inoculating menstrua (0.9%, w/v), apparently prevented the attachment of Salmonella to chicken skin. However, when Lillard (90) repeated the experiments of Thomas and McMeekin (128) using both SEM and conventional culture techniques, she could not confirm the earlier results. The bacterial cells in saline inoculum apparently attached in crevices in the tissue itself, where they were not visible by SEM. Appl and Marshall (16) reported that 0.1 M KCl solutions removed three times as many Pseudomonas cells from beef cubes as a water rinse, as determined by bacterial populations in the rinse water. DeLaquiss and McCurdy (36) investigated the role of sodium, potassium, and calcium chlorides in attachment and colonization of beef muscle surfaces. These researchers reported that attached cell densities increased at significantly faster rates on meat treated with calcium chlorides, when compared to the other two salts.

The attachment process is a complex phenomenon which, at present, is not fully understood, although properties of the individual bacterial cell and substrate affect the rate and degree of this process. Thomas and McMeekin (129) reported that bacterial attachment to chicken muscle was influenced by water uptake of the tissue. Lillard (89) reported that water uptake by chicken tissue was in two distinct phases, surface film and tissue uptake, and that over time, bacteria moved from the surface film to the tissue. However, under actual processing conditions, Lillard (87) could find no difference in bacterial attachment to chicken skin at different stages of processing.

Intrinsic properties of the bacterial cell also affect attachment to tissue surfaces. As previously noted, the effect of motility or flagella is controversial. Lillard (88) reported that the phenomenon of bacterial attachment to chicken skin involved mechanisms other than fimbriae or flagella. DeGraft-Hanson and Heath (35) reported that treatment of Pseudomonas cells with d-mannose reduced cell activity, indicating an effect on flagella, but did not reduce attachment to poultry skin. Dickson and Koohmaraie (45) reported that the relative negative charge on the bacterial cell wall was correlated with attachment to beef tissue, although the correlation was greater with lean than fat tissue. There was some correlation between relative hydrophobicity of the bacterial cells, as determined by bacterial adherence to hydrocarbons, and attachment to fat tissue. Chung et al. (26) reported no competitive interactions between several strains of spoilage and pathogenic bacteria during attachment to beef lean or fat tissue. The different bacteria neither enhanced or interfered with the attachment of the other bacteria.

Previous researchers with bacterial attachment to poultry (89,128) and beef (22,40) tissue surfaces have used liquid attachment medium as a method of inoculation. This is an appropriate method for inoculation for poultry because it simulates conditions commonly found in the chilling process with poultry processing (91), which is a significant source of contamination. However, since most contamination of beef carcasses results from solid or semisolid
material, the use of a liquid inoculation system may not be representative of contamination under beef processing conditions. Bacterial contamination of beef tissue by inoculated manure has been studied (46), with fewer bacteria being deposited on the surface over time from the manure than from a liquid inoculation system. These differences suggest that an appropriate inoculating system must be used relevant to the animal species being studied. The transfer of bacteria between beef tissue surfaces has also been documented (41), with the numbers of bacteria transferred decreasing as the length of time the initial inoculum was allowed to adsorb onto the base tissue increased.

**CARCASS SANITIZATION**

**Water rinsing**

Physically removing bacteria remaining on carcass surfaces by washing with water and subsequent sanitizing has been shown to be a practical and effective means of improving the microbiological quality of fresh meat (13, 83). Washing the animal prior to slaughter with cold (52) or hot (107) water, as well as carcass washing, brushing, and drying combinations (106) have all been reported to reduce the population of bacteria on carcasses. Smith and Graham (121) reported that dipping beef or mutton samples in 80°C water for 10 s killed more than 99% of an inoculated population of *E. coli* or salmonellae. The researchers noted that, when sheep carcasses were processed using this treatment, there was some initial, temporary discoloration of the carcass surfaces. This immersion treatment was modified to a spray system, although the water temperature had to be raised to 90°C so that a carcass surface temperature of 80°C could be achieved (54). However, Notermans and Kampelmacher (102) reported that *E. coli* and *Salmonella oranienburg* were more resistant to hot water when attached to poultry skin than when they were not attached.

Kotula et al. (83) reported that increasing the water pressure during washing from 4.2 kg/cm² (85 kPa) to 24.6 kg/cm² (498.5 kPa) significantly reduced surface microflora of carcasses, to levels comparable to those produced by washing at low pressure with hot (51.7°C) water. These results were contradictory to those of Smith et al. (120) and Patterson (108), who reported that elevated pressures were less desirable. A potential concern with increasing washing pressures is that bacteria could be physically driven into the tissue of the carcass itself. De Zuniga et al. (39) developed a model system to study this phenomenon, using an insoluble Blue Lake dye. They reported that increasing pressures generally resulted in increased depth of penetration of the dye and recommended that washing pressures for beef carcasses not exceed 2070 kPa. Carcass washing and sanitizing processes have been automated (5) and the physical parameters involved in this process have been extensively studied (30). However, these previous reports have evaluated washing and sanitizing in regard to natural contamination, where the nature and physiological state of the contaminating microflora are unknown.

**Chlorine**

Kotula et al. (83) washed beef carcasses with various combinations of 200 mg/L chlorine solutions at either 12.8 or 51.7°C over a pH range of 4 to 7. The researchers sampled at 45 min and 24 h after treatment and reported log₁₀ reductions in total aerobic bacteria of 1 to 2 cycles after 45 min and greater than two cycles after 24 h. When the wash pressure was increased from 4.2 to 24.6 kg/cm² (85 to 498.5 kPa), the log₁₀ reductions in total aerobic bacteria were greater than 2 and 3 log₁₀ cycles after 45 min and 24 h, respectively. Kelly et al. (78) evaluated the use of 30 and 95 mg/L chlorine sprayed at 50, 65, and 80°C on lamb carcasses. A water rinse with 80°C water was approximately equivalent to 95 mg/L chlorine at 55°C in reducing bacterial populations, with greater reductions reported for 65 or 80°C with 30 mg/L chlorine. These researchers concluded that the effects of water temperature and chlorine concentration were additive. Increasing the wash time enhanced the effectiveness of the chlorine washes but had no additional effect with hot water only. In a later publication (79), the authors reported the results of having sprayed lamb carcasses with 450 mg/L chlorine at 80°C. Although there were immediate reductions in the bacterial populations, there was generally no difference in counts between treated and untreated carcasses after 7 d. Skelly et al. (119) sprayed pork carcasses with 200 mg/L sodium hypochlorite for 10 min and reported a 1.5 log₁₀ reduction in psychrotrophic bacteria on the treated carcasses.

Smith et al. (120) reported reductions in bacterial populations of 1 log₁₀ cycle on lamb carcasses washed with 200 mg/L chlorine plus 2% acetic acid. Although these reductions were less than those reported by other researchers, differences in the sensitivity of the initial microflora to chlorine between the two experiments probably account for the different results. Smith et al. (120) also reported that chlorine decontamination was most effective in reducing bacterial growth when applied to the carcass immediately postmortem. Emswiler et al. (53) washed market beef forequarters with 100, 200, and 400 mg/L electrically generated chlorine and reported reductions of 1.45, 1.64, and 1.83 log₁₀ cycles, respectively, after 24 h. The researchers noted that chlorine from other sources, such as calcium hypochlorite and chlorine dioxide, was less effective. However, Marshall et al. (96) reported that the reductions in total aerobic counts on beef treated with hypochlorite sprays, from either electrically generated or commercial sources, were not significantly different.

Although previously cited research reported reductions in bacterial populations on carcasses attributable to chlorine sprays, some researchers have found no significant effect of chlorine sprays. Stevenson et al. (126) reported no difference in the populations of coliforms, staphylococci, or total aerobic bacteria on beef carcasses sprayed with 200 mg/L chlorine. These researchers attributed the lack of observed reductions to the low initial bacterial populations on their carcasses, and also to differences in experimental design and data analysis, when compared to other published reports. Titus et al. (131) reported an initial reduction in mesophilic and psychrotrophic populations on beef sprayed with up to 200 mg/L hypochlorite, but that there was no difference in these populations between control and treated samples after 8 d of storage. Johnson et al. (77) also reported no significant difference in total aerobic or lactic
acid bacteria populations between beef forequarters sprayed with 200 mg/L hypochlorous acid and a similar control group, and speculated that the lack of effect could be attributable to the low initial counts on the forequarters. The differences in initial microflora and experimental design make direct comparisons of many of the reports on carcass sanitizing difficult to compare directly.

Organic acids

Organic acids, such as acetic or lactic acids, have been used to sanitize carcasses because they exhibit good bactericidal activity \((1,11)\) and are generally regarded as safe (GRAS) additives \((58)\). Khan and Katamay \((80)\) determined the degree of inhibition of fatty acids against salmonellae in meat and bone meal. The researchers concluded that short-chain fatty acids had an antagonistic effect on a mixture of salmonellae strains. Chung and Goepfert \((25)\) evaluated 13 acids in inhibiting salmonellae in laboratory media and found acetic and propionic acids to be most effective. Ockerman et al. \((103)\) used acetic and lactic acid sprays in concentrations from 6 to 24% on lamb carcasses and reported that 18% acetic acid was the most effective in reducing bacterial populations. However, the researchers also noted that concentrations in excess of 12% produced bleaching of the carcasses. The reductions in total aerobic populations did not exceed 1 log\(_{10}\) cycle.

Woolthuis et al. \((135)\) immersed porcine livers in 0.2% lactic acid for 5 min and found significant reductions in total colony and Enterobacteriaceae counts after 1 and 5 d, when compared to untreated control samples. Woolthuis and Smulders \((136)\) evaluated lactic acid in concentrations of 0.75 to 2.5% on calf carcasses and determined that 1.25% acid resulted in substantial reductions in total aerobic counts with minimal carcass discoloration. This concentration reduced total aerobic bacteria by approximately 1 log\(_{10}\) cycle, with similar reductions in Enterobacteriaceae. Smulders and Woolthuis \((123,124)\) also reported calf carcasses sanitized with 1.25% lactic acid had significantly lower total aerobic populations than control carcasses after 14 d, and that there was some residual bactericidal effect of the lactic acid. Snijders et al. \((125)\) concluded that the use of lactic acid sprays as a terminal process in carcass processing could provide significant microbiological advantages. Visser et al. \((133)\) used 2% lactic acid to decontaminate veal tongues and reported decreases in the total bacterial populations of almost 3 log\(_{10}\) cycles. Gill and Newton \((63)\) reported that the inhibitory action of lactic acid was primarily attributable to low pH and not to action of the undissociated acid. Smulders et al. \((122)\) reviewed the literature on sanitizing meat with lactic acid and recommended that public health authorities allow the use of lactic acid as a decontaminating agent.

Reynolds and Carpenter \((112)\) sprayed pork carcasses with a 60:40 mixture of acetic and propionic acids and reported a 2 log\(_{10}\) reduction in total bacterial populations. Osthold et al. \((104)\) developed an acid spray consisting of acetic, lactic, citric, and ascorbic acids and reported that it had a selective inhibitory effect on Enterobacteriaceae. Bell et al. \((18)\) determined the effectiveness of 1.2% acetic acid and a mixture of 0.6% acetic and 0.046% formic acids.

The researchers found that the acetic/formic acid mixture was as effective a bacteriocidal agent as the higher concentration of acetic acid, without adverse effects on the product. Rubin \((115)\) reported that lactic and acetic acids were slightly synergistic in their inhibitory effects on Salmonella typhimurium. Adams and Hall \((2)\) also noted an apparent synergistic interaction between acetic and lactic acids, which they concluded was a result of the potentiation of acetic acid in the lower pH environment created by the lactic acid. The interactions among acid type, concentration, and application temperature have been studied on lamb carcasses \((4)\) and beef tissue \((7,8)\). These researchers also evaluated a mixture of 2% acetic, 1% lactic, 0.25% citric, and 0.1% ascorbic acids and concluded that the acid mixture was no more effective than either acetic or lactic acid in similar concentrations \((9)\). Typically, the bactericidal effectiveness increased with increases in concentration or temperature. Lactic acid solutions have also been applied to poultry \((132)\), with immediate reductions of approximately 1 log\(_{10}\) cycle in bacterial populations. Zeitoun and Debrevere \((137)\) applied 10% lactic acid, buffered to pH 3.0, to extend the shelf life on chicken legs from 6 to 12 d. When the microflora on beef tissue was subjected to osmotic stress, either by physical or chemical dehydration, the effectiveness of acetic acid was dramatically enhanced \((42)\).

Organic acids have been reported to have an immediate effect on the microflora of meat products, primarily when applied during the slaughtering and dressing applications. However, application of the acid after fabrication of individual cuts of meat has little impact on the ultimate microflora. Acuff et al. \((1)\) and Dixon et al. \((48)\) reported that steaks or loins decontaminated with acid sprays did not differ in total aerobic populations after storage and simulated retail display. In addition, Lillard et al. \((92)\) reported that addition of acetic acid to poultry scald water did not reduce the populations of bacteria on the carcasses, although there were reductions in bacterial populations in the water itself.

Other sanitizers

Other compounds have been evaluated for their ability to sanitize animal carcasses. Gompututra and Fabian \((67)\) used chloramphenicol to control the numbers of staphylococci and salmonellae on inoculated lean beef and pork, with marginal results. These authors concluded that 4% acetic acid was more effective in reducing the populations of these test organisms, which is significant since chloramphenicol is not allowed in food for human consumption. Biemuller et al. \((20)\) found that hydrogen peroxide, stannous chloride, acetic acid, and steam were effective in reducing populations of salmonellae and total bacteria on carcasses, but that some treatments produced unacceptable changes in the carcass appearance. Anderson et al. \((12)\), who compared a quaternary ammonium compound (QUAT) to sodium hypochlorite and 4% acetic acid, found that the QUAT reduced the total aerobic populations by less than 0.5 log\(_{10}\) cycles. They concluded that acetic acid was more effective in reducing bacterial populations than the other sanitizers.
Thomson et al. (130) added 10 or 25 mg/L poly [hexamethylene-biguanide hydrochloride] (PHMB) to a simulated poultry chill system and experimentally inoculated *Salmonella* onto chicken carcasses. They reported that 25 mg/L PHMB prevented cross-contamination in the chiller but that viable salmonellae remained on the carcasses. Sheldon and Brown (117) treated poultry chiller water with ozone. Ozone significantly reduced the populations of bacteria in the chiller water but only slightly reduced the populations on the carcasses when compared to conventional water chilling.

Morrison and Fleet (99) immersed inoculated chicken carcasses in water or 2.5% potassium sorbate for 10 min (both at 60°C). However, there was little additional effect attributable to the potassium sorbate. However, Kondaiah et al. (82) immersed inoculated beef into three different mixtures containing potassium sorbate (up to 20% w/v) for 1 min and reported that these treatments significantly reduced the populations of *E. coli*, *Staphylococcus aureus*, *Streptococcus fecalis*, *Clostridium perfringens* when compared to samples immersed in water. Humphrey et al. (74) reported that adjusting the pH of poultry scald water to pH 9.0 with sodium hydroxide reduced the total numbers of aerobic and “coli-aerogenes” bacteria on chicken carcasses. Dickson (40) reported that washing lean and fat beef tissues with concentrated sodium or potassium hydroxide reduced the populations of *S. typhimurium* and *Listeria monocytogenes* by 2 to 3 log10 cycles and 1 to 2 log10 cycles, respectively.

Other processes

Most research in sanitizing red meat carcasses has focused on a single carcass treatment in the abattoir, usually as a final process before the carcasses are chilled. However, patents were recently issued for a process involving multiple washing and sanitizing treatments at different points in the slaughter process (27,28). This process includes a wash and sanitizing treatment immediately after removal of the hide, followed by a second treatment after the carcass is eviscerated and split. The intent of this process is to physically remove contaminants and then sanitize the carcass immediately following hide removal and evisceration. Dickson and Anderson (44) found that pre- and postevisceration washing with 55°C acetic acid would reduce the populations of *Salmonella california* by greater than 2 log10 cycles on beef tissue in a model system, although there was some apparent recovery of injured bacteria when the tissue was exposed to a simulated spray chill protocol. Prasai et al. sprayed beef (109) and pork (110) carcasses with 55°C 1% lactic acid after hide removal (beef) or dehairing (pork), after evisceration, or at both locations during processing. There was an immediate reduction in aerobic plate counts of approximately 1 log cycle on acid sprayed beef carcasses when compared to control carcasses (109), although the location of the spray treatment was not as important as the presence or absence of the treatment. However, the aerobic plate counts of vacuum-packaged loins from both treated and untreated carcasses were not significantly different after 3 and 14 d of storage at 3°C. Aerobic plate counts on acid sprayed pork carcasses, while numerically lower than those of the control carcasses, were not significantly different (110).

In modern commercial beef processing, cold water is misted on the carcasses at specified time intervals. The cold water mist increases cooling rates by evaporative cooling and reduces the moisture loss of the carcasses. Spray chilling was used initially as a method of sanitizing carcasses with chlorine (72,127). Hamby et al. (70) incorporated 1% acetic or lactic acid into the spray chilling process and reported significant reductions in total aerobic populations on treated carcasses when compared to untreated carcasses. Dickson (43) used 0.5, 1.0, and 2.0% acetic acid in different spray cycles and reported reductions in the populations of *S. typhimurium*, *L. monocytogenes*, and *E. coli* 0157:H7. Alternative processes, such as gamma irradiation, have been shown to be highly effective in controlling bacterial pathogens in meat (86,100). However, irradiation does not remove physical contaminants such as hair or bone dust.

**EQUIPMENT**

Carcasses have commonly been washed with water from a single hand-held nozzle. This procedure was inefficient, in that some areas of the carcass could be missed and that a single stream of water could simply shift foreign material from one location on the carcass to another without actually removing it. Kurt (84) realized the need for a mechanical washing apparatus. He patented a device in 1938 and an improved version in 1951 (85). Ekstam and Johnson (50) designed and built a hog scalding and sanitizing device which used wet steam. In 1965, Kolman (81) obtained a patent for an automated carcass washer which he stated would thoroughly clean an animal carcass. Other designs in larger slaughter operations have incorporated washing units which consisted of opposed stationary nozzles into the slaughter processing line. Gage et al. (59) patented a carcass washer employing banks of spray nozzles which oscillated up and down, with the upward motion limited to not more than a 90 degree angle from the vertical supports. Anderson and Marshall (6) conducted studies on the basic physical parameters of spraying, including volume, line pressure, angle of droplet impact, mean droplet size, total force of spray, and speed of travel through the washer. Later, the effects of nozzle size and configuration on water uptake by meat were evaluated (15). These data were used in the design, construction, and patenting of an automated carcass washing system (10,11). The unit was later modified with a “no-door” enclosure (14) and an inexpensive self-cleaning device (3). Davey (33) developed a theoretical analysis of two hot water cabinet decontamination systems, and a refined hot water wash cabinet was subsequently designed, fabricated, and tested (32,34).

**SUMMARY**

Microbial contamination of food animal carcasses can be minimized by good manufacturing practices in the abattoir. However, under modern processing conditions, the
production of pathogen-free meat cannot be guaranteed. A decontamination step, in the form of washing and sanitizing during the slaughter process, can improve the microbial safety and shelf life of the meat and should be considered an integral part of the production process.

REFERENCES


