

2017

Maintaining the safety and quality of beef carcass meat

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Abstract

Contamination of animal carcasses during slaughtering procedures is undesirable, but unavoidable in the conversion of live animals to meat for consumption. Internal muscle tissues are essentially sterile, and most initial contamination of red meat carcasses is contributed by the hide during removal (Elmonssalami and Wassef, 1971; Gill and Penny, 1979; Gill et al., 1976). The exposed surface of the hide and the hair accumulate dust, dirt and faecal material, and this is the primary source of bacterial contamination during slaughter (Ayres, 1955; Shotts et al., 1961). The factors that affect the extent of this contamination are reviewed by Patterson (1969) and Grau et al. (1968). Much of the microflora transferred to the tissue surfaces, while aesthetically undesirable, is nonpathogenic; however, pathogens such as Salmonella, Campylobacter and pathogenic Escherichia coli can be present.

Disciplines

Agriculture | Animal Sciences | Food Processing | Meat Science

Comments

This is a chapter from Dickson, J.S. and G.R. Acuff. 2017. *Maintaining the Safety and Quality of Beef Carcass Meat*. IN *Ensuring safety and quality in the production of beef*. Volume 1: Safety. 2017. Acuff, G.R. and J.S. Dickson (editors). Burleigh Dodds Science Publishing. Sawston, Cambridge, UK. doi: [10.19103/AS.2016.0008.12](https://doi.org/10.19103/AS.2016.0008.12). Posted with permission.

Maintaining the safety and quality of beef carcass meat

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1 Introduction

Contamination of animal carcasses during slaughtering procedures is undesirable, but unavoidable in the conversion of live animals to meat for consumption. Internal muscle tissues are essentially sterile, and most initial contamination of red meat carcasses is contributed by the hide during removal (Elmonssalami and Wassef, 1971; Gill and Penny, 1979; Gill et al., 1976). The exposed surface of the hide and the hair accumulate dust, dirt and faecal material, and this is the primary source of bacterial contamination during slaughter (Ayres, 1955; Shotts et al., 1961). The factors that affect the extent of this contamination are reviewed by Patterson (1969) and Grau et al. (1968). Much of the microflora transferred to the tissue surfaces, while aesthetically undesirable, is non-pathogenic; however, pathogens such as *Salmonella*, *Campylobacter* and pathogenic *Escherichia coli* can be present.

2 Process flow description

The slaughter process begins when the animals are unloaded from the trucks which bring them to the slaughter establishment. The animals are typically held in holding pens (lairage) for several hours to reduce transportation stress. Although the lairage pens are livestock pens and not sanitary food production areas, they still require routine removal of faecal material and uneaten food to prevent excessive contamination of the animals prior to the actual slaughter process. If the lairage pens are uncovered, they should be located in such a place that they drain well during rainy seasons. Although these steps are important in regard to animal welfare, they also have an impact on the safety and quality of the meat, in that they minimize additional contamination of the hide prior to slaughter. Since the hide is a significant source of carcass contamination, minimizing contamination of the hide can help minimize subsequent contamination of the carcass.

The slaughter process proceeds as the animals are moved from the lairage pens to the slaughter floor. The animals are moved with as little stress as required, to minimize stress-related quality defects in the meat. The next two steps – humane stunning and exsanguination – occur in rapid succession. The carcasses are typically allowed to bleed out for approximately 5 to 6 minutes. Other than maintaining the hygienic quality of the stick knives, there are no other processes which either contribute to or reduce safety or quality issues during these two steps.

The impact of sticking on contamination is not clear. A classic study by Jensen and Hess (1941) evaluated the process of sticking, and suggested that bacteria could enter the bloodstream during the sticking. These conclusions were based on the fact that fewer bacteria were found in the blood retained in the hearts of hogs 'sterilely' stuck, as compared to those that were septicly stuck. However, they also noted that when cultures of *E. coli* were added to blood drawn from a live hog, the bacteria could not be recovered after two to five hours, and they attributed this to the bactericidal activity normally associated with blood. For bacterial pathogens to enter the bloodstream during the sticking operation, several events would have to occur. The first is that pathogens would have to be present at the exact point of the stick wound. Secondly, the bacteria would have to be carried into the bloodstream of the animal by the knife, either from previous contamination or from material at the site of the stick wound. Research has shown that salmonellae may be carried on improperly sterilized knives (Peel and Simmons, 1978). While there might be a reasonable probability of these events happening, the individual cells would be rapidly dispersed throughout the entire bloodstream, resulting in a rapid dilution of the initial population. This dilution, coupled with the documented bactericidal properties of the blood, suggests that the stick would not be a major source of salmonellae contamination of the muscle tissue. In addition, the site of the stick wound itself is normally trimmed out at a later point in the process, removing any bacteria which may have adhered to the tissue.

In some slaughter processes, the hides of the carcasses are sprayed or washed with water prior to further processing. The objective of this step is dependent upon current environmental conditions. Under dry environmental conditions, a light water spray may be applied to the hides to minimize dust during the hide removal operation. This reduces contamination of the meat by reducing the dust which may be generated by mechanical hide removal. The airborne dust may be contaminated with bacteria which may impact either the quality or safety of the carcass. In wet environmental conditions, the carcasses may be heavily contaminated with mud and manure. In this case, a more forceful washing

system may be employed to remove some of this external contamination from the surface of the hide. Although the wash does not remove all of the contamination, an incremental decrease in hide contamination may result in less contamination of the carcass as it proceeds through the remainder of the slaughter process. Implementation of hide wash systems that apply antimicrobial solutions has been reported to reduce the presence of enteric pathogens on carcass surfaces (Arthur et al., 2007; Bosilevac et al., 2005), and Yang et al. (2015) reported that hide decontamination could reduce transfer of *E. coli* to carcass surfaces during dehiding processes.

The next step in the process is the removal of the hide. The hide may be removed by hand; however, in many large slaughter establishments hide removal is a mechanically assisted process. When the hide is removed from a carcass during slaughter/dressing procedures, the sterile surface protected by the hide is exposed and then subsequently contaminated with bacteria that most likely originate from the hide, gastrointestinal tract or slaughter plant environment. After hide removal, the head and viscera are removed, which may lead to additional contamination. Although good dressing practices will minimize this contamination, it is almost impossible to prevent microbial contamination from occurring during these steps. Most bacteria contaminating the surface will be exposed and vulnerable to chemical decontamination treatments; however, some may have been forced into small cuts just under the surface of the carcass, or flaps of tissue may hang after disconnecting from the removed hide such that the bacteria are covered. These cells may be positioned such that they are protected from exposure to chemicals used for decontamination of the surface. In addition, a newly exposed carcass surface is typically warm, soft, moist and tacky, but evolves after cooling to a hard, dry surface. Temperature of the carcass surface, presence of a moist surface or water film and solidification of fat surfaces during cooling all likely affect the ability to decontaminate. This chapter specifically addresses chilled carcass surfaces through fabrication and packaging, likely some of the more difficult surfaces to successfully apply an intervention. The meat surface is cool, bacteria have likely begun to attach and they may be embedded within solidified fatty tissues.

3 Bacterial attachment to meat surfaces

Bacterial attachment to meat tissue is a complex mechanism which may have a practical effect on the transfer of pathogens between carcasses, the effectiveness of sampling methods and the performance of treatments for carcass decontamination.

Meat decontamination is usually achieved by sprays or washes with water or antimicrobial solutions. Depending on the treatment applied, the reduction in microbial numbers on the meat surface will be due to physical removal of the microorganisms, a killing effect of the decontaminating solution or a combination of both factors. Among the factors influencing the effectiveness of carcass interventions, bacterial attachment onto the meat surface has attracted the attention of many researchers. The molecular basis for bacterial attachment has been reviewed by Hardin (1995). Fratamico et al. (1996) reported that, once bacteria are attached to meat, rinse solutions such as acetic acid or trisodium phosphate (TSP) were not effective in removing a large part of the contaminating bacteria. In contrast, Castillo et al. (1998a) and Hardin et al. (1995) did not find any differences in populations of *E. coli* O157:H7 or *S. Typhimurium* on beef carcass surfaces treated by hot water or organic acids immediately or 20–30 min after contaminating the beef surfaces. Since bacterial attachment on carcass surfaces has been reported to occur within 20 min of contact, Butler

et al. (1979) concluded that bacterial attachment did not affect the antimicrobial effect of hot water or organic acid sprays against pathogens on beef.

Other factors, such as the surface fat characteristics of the carcass region, may be more important regarding effectiveness of antimicrobial sprays. Using transmission and scanning electron microscopy, Mattila and Frost (1988) described the attachment of *E. coli* to beef and chicken surfaces. The effect of the surface fat characteristics of the meat is important because fat, being hydrophobic, may interfere with the effectiveness of water washes to remove bacterial contamination. In contrast to the above reports, Dickson (1991a) found more attachment of *S. Typhimurium* and *L. monocytogenes* to lean tissue than to fat tissue. He also found organism-intrinsic factors, such as inoculum size, temperature at which the cells had been exposed before attaching and age of the cells, to have a significant effect on the attachment of these pathogens to beef surfaces. Bouttier et al. (1997) also studied the role of bacterial flagella on attachment to meat surfaces by determining the number of cells of *Salmonella Choleraesuis* adhering to lean or fat tissue after treating with antibodies to flagellar antigens. The count of attached cells was significantly lower for antibody-treated cells than that of control cells or cells treated with antibodies to somatic antigens. Although this would indicate that flagella have an effect on bacterial attachment, other experiments involving potential chemical receptors on beef tissues saturated by a suspension of flagella showed no effect of flagella on the attachment of *S. Choleraesuis*. This demonstrated that the surface of beef did not possess any receptors for the flagella of this species. Butler et al. (1979) reported greater attachment of Gram-negative, motile cells than Gram-positive or non-motile bacteria. Cells that are attached to meat surfaces have been shown to transfer between surfaces at a lower rate than unattached cells, although the highest transfer rate was observed from adipose to lean tissue (Dickson, 1990). This is of practical importance because carcasses are often in close contact for a lengthy time in coolers, and cross-contamination may occur during storage. The presence of organic matter may be another factor affecting the extent of bacterial attachment on meat surfaces. Dickson and MacNeil (1991) reported greater attachment of *S. Typhimurium* and *L. monocytogenes* to beef carcass surfaces when the inoculum had been diluted in phosphate buffer compared to cow manure. The nature of the inoculum needs to be taken into consideration when research is conducted involving inoculation of pathogens onto meat surfaces.

4 Decontamination methods

4.1 Knife trimming

Current USDA-FSIS regulations require that all faeces, ingesta and milk must be physically removed from beef carcasses by knife trimming or, when such contamination is less than one inch in its greatest dimension, by vacuuming with hot water or steam (Federal Register, 1996). The traditional approach of trimming contamination from beef carcasses has been evaluated for efficacy by several authors. Gorman et al. (1995b) reduced the aerobic plate counts (APC) and *E. coli* counts on inoculated beef brisket 2.0 to 2.5 log₁₀ ($P < 0.05$) by knife trimming without any other combined treatment. Application of a water wash subsequent to trimming achieved no additional reduction unless the water temperature was at least 66°C. Other authors have also reported reductions of bacterial counts through trimming (Gorman et al., 1995a; Hardin et al., 1995; Prasai et al., 1995a, b; Reagan et al.,

1996); however, in most instances the evaluations of decontamination by knife trimming have been performed under laboratory conditions. Prasai et al. (1995b) concluded that an observed large bacterial reduction demonstrated by trimming might have been due to the artificial conditions under which this operation was accomplished. In their work, the trimming samples were collected from locations that had been completely trimmed by making one cut using a sterile knife, a procedure not likely to be comparable to the trimming performed in plants during normal slaughter operations. In a study conducted within a beef packing plant, Gill et al. (1996) reported no differences in total bacterial and *E. coli* counts from carcasses sampled before and after trimming. These authors also found that a water wash treatment subsequent to trimming did not produce further reduction in bacterial counts, concluding that the reduction in bacterial numbers achieved by either trim or water wash is insufficient to enhance the safety of the meat. These reports may indicate that although trimming has been reported to significantly reduce bacterial counts under laboratory conditions, the circumstances under which slaughter plants typically perform this operation may not achieve the expected carcass decontamination. In addition, spread of bacterial contamination from non-visible areas of faecal contamination to other clean areas during trimming is a concern (Hardin et al., 1995).

4.2 Water wash

Washing of carcasses with water after slaughter is a common practice in beef slaughter, with the intent of removing visible contamination from carcasses and improving the visual quality of the meat. Under the USDA-FSIS zero-tolerance policy for faecal contamination, only knife trimming and, to some extent, steam vacuum treatments are allowed as a means to eliminate visible faecal contamination from carcasses. However, many researchers have studied the ability of water washes to reduce microbial contamination. Anderson et al. (1975) studied the effect of factors such as water volume and pressure, angle of droplet impact, droplet size, spray force and the speed at which the meat passed through the spray on the removal of the yeast *Rhodotorula rubra* on beef plate meat. Factors such as water pressure, water flow rate and speed of movement of meat through spray had significant effect on microbial removal, whereas mean droplet size was not a significant factor. The angle of droplet impact was not significant when the pressure was 28 kg/cm² but became significant as the pressure was decreased. Contrasting the findings of Anderson et al. (1975), Crouse et al. (1988) did not find any reduction in numbers of *Enterobacteriaceae* or APC on beef carcasses as affected by the spray pressure or the chain speed. In a similar study, DeZuniga et al. (1991) found no significant differences due to pressure for the reduction in APC or counts of *Enterobacteriaceae* on meat surfaces.

DeZuniga et al. (1991) also addressed the effect of high-pressure water wash on bacterial penetration into the meat. Using an insoluble dye (Blue Lake) with a particle size slightly smaller than most bacteria, these authors reported that the depth of the dye penetration after an automated water wash was directly proportional to the line pressure, and that the type of nozzle used had a significant effect on penetration of Blue Lake at pressures above 4,140 kPa. DeZuniga et al. (1991) concluded that bacteria might similarly penetrate into the meat as a result of high-pressure cabinet water wash treatment. Of significance is the possibility that if a sanitizer is used after washing for decontamination purposes, the solution might not reach bacteria implanted within the meat by a pressured wash.

It is generally accepted that treatments with hot water (74°C) will produce a sanitizing effect rather than a simple washing effect (Federal Register, 1996). Cabedo et al. (1996)

reported larger reductions of *E. coli* on beef brisket after spraying with 74°C water compared to 35°C. However, under sublethal temperature conditions, higher temperatures would likely have an effect on fat softening, which may also affect the ability to remove bacterial contamination. Gorman et al. (1995b) produced larger *E. coli* reductions on beef tissue by spraying water at 35°C than by spraying water at 16°C. However, there were no differences in *E. coli* reductions after spraying water at 35, 66, or 74°C. When sprays at 16, 35, or 74°C were followed by a second wash at 16°C, the reductions increased with the temperature of the first wash, possibly indicating that a warm carcass wash would be more helpful than a cold wash in removing microbial contamination, especially if the water wash is followed by a sanitizing step.

4.3 Trimming versus washing

Many studies evaluating trimming as a means of reducing bacterial contamination compare the reductions obtained by water washing, and indicate that trimming produces similar or larger reductions than those obtained by water wash (Gorman et al., 1995a; Hardin et al., 1995; Prasai et al., 1995b). The USDA-FSIS affirms that trimming, if performed properly, will effectively remove the visible contamination as well as any accompanying microbial contamination, whereas, if not properly conducted, may spread the contamination to other newly exposed areas (Federal Register, 1996). However, Gill et al. (1996) reported that numbers of *E. coli*, coliforms and aerobic bacteria that contaminate beef carcasses during dehiding and evisceration were not reduced by trimming, and were halved by washing. Conversely, Reagan et al. (1996) showed a significant superiority of trimming over water wash at reducing aerobic bacteria and *E. coli* biotype I on beef carcasses.

Whether trimming reduces more contamination than water wash or vice versa, neither procedure appears to be particularly effective in decontaminating carcasses. In studies where trimming and water wash are compared to sanitizing treatments for beef carcass decontamination, both water wash alone and trim alone have been reported to produce significantly smaller reductions than sanitizing agents such as hot water or organic acids (Gorman et al., 1995b; Hardin et al., 1995; Reagan et al., 1996). These studies indicate that both trimming and water washing of carcasses should not be practiced for decontamination purposes, but for carcass cleaning. Even a visually clean carcass may be contaminated with pathogenic bacteria at unsafe levels. In addition, both treatments are likely to spread pathogenic contamination to clean areas of the carcass. Therefore, trim, wash, or any other cleaning treatment, should be followed by a subsequent sanitizing treatment.

4.4 Steam vacuum

Application of hot water or steam combined with vacuuming is a commonly used carcass cleaning process that is allowed to be used instead of knife trimming to physically remove faecal contamination while sanitizing the contaminated area (Federal Register, 1996). A typical steam vacuum machine includes a vacuum wand with a build in hot water spray nozzle, which delivers water at 82 to 88°C. This internal nozzle is intended to sanitize the carcass surface as the vacuum removes the faecal material. Two external spray nozzles are positioned on the top and bottom of the wand to provide a continuous steam flow. This design would allow for steam to continuously keep the outside of the wand clean and sterile, while also helping in the carcass surface sanitation process. The steam vacuum machine has been designed to clean only small areas of contamination, and is

not applicable to clean and sanitize the entire carcass surface. Because of this limitation, applying steam vacuum treatment for carcass cleaning is permitted only when the extent of the contamination is no larger than 6.25 cm² (1 in²) (Federal Register, 1996).

Investigators have studied the efficacy of spot cleaning vacuum machines for reducing bacterial contamination on carcass surfaces. Phebus et al. (1997) observed no differences between a steam vacuum system and interventions such as steam pasteurization and knife trimming in reducing *E. coli* O157:H7, *S. Typhimurium* or *L. monocytogenes* on freshly slaughtered beef surfaces. However, these authors noted that steam vacuum is a localized cleaning device, whereas steam pasteurization is a full-carcass treatment. During in-plant evaluations of two steam-vacuuming units, Kochevar et al. (1997) found lower APC and coliform counts on carcass surfaces that had been treated with the steam vacuum unit, when compared to surfaces that had been knife trimmed. According to the results of their study, use of steam vacuum reduced microbiological contamination and improved visual appearance of carcasses for which otherwise knife trimming would have been required by the inspector. In a review on procedures for beef carcass decontamination, Dorsa (1997) described an in-plant testing of steam vacuum, designed to determine its efficacy under industrial use, indicating that a steam-vacuuming unit consistently reduced bacterial populations from contaminated areas of less than 2.5 cm. From these results, he concluded that a commercial steam vacuum system could perform better than knife trimming for removing bacterial contamination on beef carcasses.

5 Decontamination treatments: hot water and organic acids

5.1 Hot water

In contrast to regular water washes, sprays with water at temperatures above 74°C may be used as sanitizing interventions. The effect of applying hot water versus washing carcasses with warm water was reported by Smith (1992), finding an average 0.2-log₁₀/cm² reduction of various pathogens on fresh meat after washing with 40°C water, but reporting a reduction of 3.1 log₁₀/cm² after applying 80°C water. Multiple reports indicate that the application of hot water treatments can effectively reduce microbiological contamination on meat carcasses, and several studies also report that washing carcasses with water at temperatures greater than 80°C will not produce permanent discolouration of the carcass surface (Barkate et al., 1993; Patterson, 1969; Smith and Graham, 1978). In an early report on hot water decontamination, Patterson (1969) reported that beef carcasses treated with a steam and hot water spray (80–96°C) for 2 min contained significantly lower bacterial numbers than untreated carcasses. A volume of 18.9 L of water was sprayed on each carcass; however, the actual temperature at the carcass surface during the treatment was not provided. Smith and Graham (1978) reported that pouring hot water (80°C) on beef and lamb samples for 10 s destroyed more than 2 logs of *E. coli* and *Salmonella* inoculated at levels of 6.5 log₁₀/cm². In a laboratory evaluation of a hot water cabinet, Davey and Smith (1989) obtained *E. coli* reductions of approximately 3 log₁₀/cm² for artificially contaminated beef carcass sides treated with hot water that elevated the carcass surface temperature to 83.5°C for 20 s. Kelly et al. (1981) reported that lamb carcasses sprayed with hot water at temperatures above 80°C caused significant decreases (>1.0 log₁₀/cm²)

in APC. Dorsa et al. (1996b) and Gorman et al. (1995b) reported reductions in coliform or *E. coli* counts of approximately $3.0 \log_{10}/\text{cm}^2$ when evaluating hot water treatments.

Proper design of a hot water treatment for carcass treatment is of paramount importance for obtaining effective reduction in bacterial populations, as loss of heat within the spray from the nozzle to the carcass surface may be so great that the carcass surface receives an insufficient temperature increase. Barkate et al. (1993) sprayed areas of hot beef carcass surfaces using 95°C water with the objective of raising the carcass surface temperature to 82°C for approximately 10 s and bacterial contamination on the carcass surface was reduced significantly. Problems reported in applying hot water included designing a water spray that would adequately attain a bactericidal temperature at the surface of the carcass. The volume of the spray and the size of the water droplets were reported to greatly affect the temperature of the water from the point of origin at the spray nozzle and prior to contacting the carcass surface. Using a type of nozzle which addressed the limitations reported by Barkate et al. (1993), Castillo et al. (1998a) sprayed hot water onto different hot carcass surface regions, obtaining average reductions of initial counts for *E. coli* O157:H7 and *S. Typhimurium* of 3.7 and 3.8 \log_{10}/cm^2 . Corresponding reductions for APC and counts of coliforms and thermotolerant coliforms in their study were 2.9, 3.3 and 3.3 \log_{10}/cm^2 , respectively. In this study, the hot water spray was combined with a previous water wash at 35°C, which significantly improved the visual quality of the carcass surfaces.

5.2 Organic acids

Among different organic acids, acetic and lactic acids were more extensively used for carcass decontamination. The effectiveness of these two acids, as well as other carcass interventions was reviewed by Dickson and Anderson (1992). In an early study on pork carcass decontamination, Biemuller et al. (1973) reported that spraying carcasses with acetic acid at pH 2.0 for 30 or 60 s resulted in large reductions of naturally occurring microflora and inoculated *S. enteritidis* on pork carcasses at a slaughter plant. Ockerman et al. (1974) also reported significant reductions in numbers of naturally occurring microorganisms on lamb carcasses by acetic and lactic acids. Additionally, these authors reported a small residual effect of the acids on the microbial numbers on the carcasses during 12 days of refrigerated storage, which was affected by the concentration and type of the acid. Anderson et al. (1977) produced reductions of 2.55 log on counts of viable microorganisms on meat by spraying 3% acetic acid. These reductions were significantly greater than the reductions obtained by spraying hypochlorite solution (200–250 ppm). Quartey-Papafio et al. (1980) sprayed beef strips with acetic acid; formic acid; and a mixture of acetic, formic and propionic acids. All treatments significantly reduced the bacterial counts with respect to untreated controls. However, the reductions were usually less than one log. Treatment with 1% formic acid produced the smallest reduction in viable counts (0.66 log), followed by a mixture of 0.5% acetic, 0.25% formic and 0.25% propionic acids (0.76 log); 3% acetic acid (0.89 log); and 2% formic acid (1.56 log). After 7 days of storage at 7°C, bacterial counts on the strips increased between 0.92 and 2.24 log, whereas the counts on untreated controls increased 4.66 log. They also reported that 5% ascorbic acid sprayed to prevent browning of meat treated with formic acid also enhanced the antimicrobial effect. Dickson (1992a) observed consistent reductions in populations of inoculated *S. Typhimurium* on lean and adipose beef tissue sprayed with 2% acetic acid, irrespective of the initial cell population. The acetic acid treatment had an immediate lethal effect on part of the population of *S. Typhimurium*, while another part

was sublethally injured. In general, the reductions in counts of different pathogens on beef, as reported by different authors, vary between 2 and 4.3 log cycles after spraying 2% acetic acid (Dickson, 1991b; Dickson and Anderson, 1991; Hardin et al., 1995; Tinney et al., 1997). Variations in reductions obtained by different investigators may be due to differences in factors such as the temperature of the acid solution, which ranged from room temperature to 55°C in these reports. In a rare report on ineffectiveness of organic acid treatments to decontaminate beef tissue, Brackett et al. (1994) found that acetic, citric and lactic acid solutions at different concentrations were unable to reduce *E. coli* O157:H7 on beef sirloin pieces, regardless of the concentration and temperature of the acid solution. These authors explained the difference in these results from other studies can be attributed to differences in methodology. In several studies, the acid treatment is applied by dipping beef pieces in acid solutions, whereas these authors sprayed the acid solutions onto the beef pieces. However, pH data in this study indicates that the inability of organic acid solutions to reduce counts of *E. coli* O157:H7 on beef was most likely due to their failure to reduce the beef surface pH to antimicrobial levels. In other similar papers, Anderson and Marshall (1990a) reduced the pH of beef dipped in lactic acid solutions, from 5.6 (untreated meat) to 3.95, and Hardin et al. (1995) obtained surface pH values on beef carcass surfaces of 2.64 to 2.88 after spraying lactic acid, and of 3.14 to 3.47 after spraying acetic acid. Even though *E. coli* O157:H7 has been reported to be resistant to low pH environments, recent studies indicate that lactic or acetic acid sprays, when applied at 55°C, can effectively reduce levels of *Salmonella* or *E. coli* O157:H7 (Castillo et al., 1998b; Hardin et al., 1995).

Studies on carcass decontamination using lactic acid indicate that this acid shows a strong antibacterial capacity. Hardin et al. (1995) reported that lactic acid was more effective than acetic acid in reducing *E. coli* O157:H7, and as effective as acetic acid in reducing *S. Typhimurium* on beef carcass surfaces. Woolthuis et al. (1984) found immersing porcine livers for 5 min in a 0.2% lactic acid solution to be significantly more effective than immersing in hot water (65°C) for 15 s in reducing total bacterial counts and lactic acid bacteria, whereas *Enterobacteriaceae* counts were reduced at the same rate after both treatments were applied. In another study, mean *Enterobacteriaceae* counts of 1.8 log₁₀ CFU/cm² were reduced to undetectable levels on calf carcasses by spraying 1.25% L-lactic acid. This treatment also reduced the APCs by 0.8 to 1.3 log₁₀ CFU/cm² depending on the carcass region treated (breast or perineum) (Woolthuis and Smulders, 1985). Prasai et al. (1991) reduced the APC of beef carcasses at two slaughter plants by ca. 2 log₁₀/cm² by spraying 1% lactic acid at 55°C after dehiding and eviscerating. However, APCs of vacuum packaged loins cut from these carcasses were not different from those of loins cut from non-treated carcasses, indicating that the quality of subprimals depends, to a large extent, on the degree of recontamination after applying carcass intervention. An European Food Safety Authority (EFSA) panel (2011) concluded, among other things, that, 'lactic acid was shown to reduce the prevalence of *Salmonella* and/or STEC/VTEC on carcasses, beef cuts and trimmings to varying degrees depending on study design and contamination level, but reductions were generally significantly higher compared to controls'.

Some researchers have reported on the impact of organic sprays on the sensory characteristics of meat. Bell et al. (1986) did not observe significant ($P < 0.05$) discolouration of beef after dipping the meat in 1.2% v/v acetic acid for 1 min. When the treatment was extended to 10 min, a concentration of 0.6% lactic acid was enough to produce significant discolouration when compared to untreated controls. A mixture

of 0.6% acetic acid and 0.046% formic acid was not different from 1.2% acetic acid in its antibacterial activity and did not produce discolouration or noticeable flavours in the meat. Garcia-Zepeda et al. (1994a) compared the changes in psychrotrophic counts and acceptability scores of chuck subprimals obtained from carcasses treated with 3% lactic acid, 200 ppm chlorine or water. Subprimals obtained from carcasses sprayed with lactic acid showed lower psychrotrophic counts but also lower acceptability scores than subprimals from carcasses treated with chlorine or water. In contrast, Goddard et al. (1996) found no differences in meat colour, fat colour or odour in beef strip loins treated with a mixture of lactic and acetic acids when compared to untreated controls. Acuff et al. (1987) found no differences in bacterial and shelf life of steaks cut from beef loins sprayed with different acid solutions and steaks cut from untreated loins. Similar results were obtained by Dixon et al. (1987) in strip loins packed in either polyvinyl chloride or high oxygen barrier films.

Different factors may impact the effectiveness of organic acid treatments for decontaminating carcasses. The ability of different organisms to acquire acid tolerance has been reviewed by Rowbury (1995). This author mentioned growth at high temperatures or acidic conditions as environmental factors inducing acid tolerance. Heat- or acid-induced acid tolerance in bacterial pathogens requires the cells remaining under specific environmental conditions for a time long enough to synthesize the outer membrane proteins required for the acquired acid tolerance (Wang and Doyle, 1998). Since the length of all treatments in carcass decontamination is reduced to few seconds, the impact of this acquired acid tolerance on the effectiveness of different carcass interventions should be evaluated. Dickson and Kunduru (1995) addressed the acid adaptation in different strains of *Salmonella* as a potential factor influencing the effectiveness of organic acid rinses on beef. All strains of acid-adapted *Salmonella* were at least as sensitive to the organic acid rinses as the non-adapted parent strains. This study also addressed the effect of acid adaptation on heat resistance in *Salmonella*. Again, no effect of acid adaptation on the heat resistance was observed for any strain of *Salmonella*. These investigators concluded that acid adaptation of salmonellae in the environment, if occurred, would not create a new hazard with the use of organic acid rinses on beef carcasses. Another factor that might affect the practical application and lethality evaluation of organic rinses against pathogens is sublethal injury. Van Netten et al. (1984) demonstrated that acid-stressed cells of various pathogenic Enterobacteriaceae can remain undetected during evaluations of organic acid rinses, so that pathogen reduction by these treatments may be overestimated.

Several studies were conducted to determine the effect of temperature and concentration of the acid solution on the reduction of meat-borne pathogens and spoilage bacteria on beef surfaces (Anderson et al., 1987, 1988, 1992; Anderson and Marshall, 1989, 1990a,b; Greer and Dilts, 1992). In all these studies the temperature of the acid solution was found to have a profound effect on the magnitude of the reductions in bacterial counts. The concentration of the acid in the sanitizing solution has generally been determined to be of minimal importance for the effectiveness of organic rinses when it is above 1% (Anderson and Marshall, 1990a; Greer and Dilts, 1992).

Other factors such as bacterial attachment, type of meat surface (lean vs. fat), rigour state, inoculating menstruum or level of inoculum have been studied in their effect on the efficacy of organic acid sprays for carcass decontamination. Dickson (1992b) did not find differences in populations of attached *S. Typhimurium* on pre- or post-rigour, lean or fat beef tissue. Two separate reports (Dickson, 1992b; Cutter et al., 1997) indicate that

rigour state (pre- and post-rigour) does not affect the removal of pathogenic bacteria following treatment with 2% acetic acid. In general, the inoculating menstruum (buffer, tryptic soy broth, rumen fluid or faeces) had no effect on reduction of *S. Typhimurium* or *E. coli* O157:H7 after spraying acetic acid onto the inoculated beef tissues. However, Dickson (1992b) observed less reduction of *S. Typhimurium* populations on fat tissue after acid treatment when the inoculum menstruum was manure. The attachment rate and type of surface tissue do not seem to impact the effectiveness of treatments for carcass decontamination. Hardin et al. (1995) found no differences in reduction of *S. Typhimurium* and *E. coli* O157:H7 in the outside round, brisket, flank and clod carcass surface regions treated with acetic or lactic acids immediately and 20 to 30 min after inoculation. The reductions of both pathogens were significantly smaller on the inside round region, which shows a surface mostly composed of lean muscle. However, as with the other carcass surface regions, no effect of bacterial attachment was observed on bacterial reductions for outside round. Similar results were reported by Castillo et al. (1998a) for beef carcass surfaces treated with hot water. Cutter and Siragusa (1994a) also reported greater reduction rates for Gram-negative organisms on fat than on lean tissues. The inoculation menstruum has been shown to affect the attachment rate as well. Dickson and Macneil (1991) reported that *S. Typhimurium* and *Listeria monocytogenes* attached to beef carcass surfaces at a higher rate when the inoculum had been diluted in phosphate buffer compared to cow manure.

In addition to lactic and acetic acids, other organic acids have been tested for ability to reduce bacterial populations on beef. Podolak et al. (1996) found that fumaric acid solutions produced greater reductions in microbial populations and growth in ground beef. In another study, these same authors found fumaric acid at concentrations of 1% and 1.5% to be more effective than 1% lactic or acetic acids in reducing populations of *E. coli* O157:H7 and *L. monocytogenes* on beef lean muscle. In contrast, Anderson et al. (1992) found lactic acid to be more effective than acetic acid or a mixture of lactic, acetic, citric and L-ascorbic acids in reducing Gram-negative pathogens on lean meat. García-Zepeda et al. (1994b) compared gluconic acid (1.5 and 3.0%), 1.5% lactic acid, and combinations of gluconic and lactic acid as fresh beef decontaminants. Beef samples were inoculated with *Lactobacillus fermentum*, treated with the different acid solutions, vacuum packaged and stored at 1°C for up to 56 d. A mixture of 3% gluconic acid combined with 1.5% lactic acid produced the lowest psychrotrophic or lactobacilli counts. However, this mixture was detrimental to the colour characteristics of the meat. A 50:50 mixture of 1.5% each gluconic and lactic acids appeared to be beneficial for the colour characteristics of the meat at display, whereas lactic acid alone effectively reduced the bacterial counts but negatively affected the redness of the meat. Cutter and Siragusa (1994a) found no differences in log reductions of *E. coli* O157:H7 and *Pseudomonas fluorescens* on beef surfaces after spraying citric, acetic or lactic acids at equal concentrations. Reynolds and Carpenter (1974) used a 60:40 w/w mixture of acetic and propionic acids, which is used as fungicide in cereal storage, for pork carcass decontamination. By modifying the molarities of these two acids, they reduced bacterial populations by 2.0 log₁₀. In general, concentrations below 2.15 M of each acid produced little effect on the visual quality of the carcasses, while achieving bacterial reductions similar to those obtained by applying the acid mixture with higher molarities. More research on the usefulness of other organic acids with reported antibacterial activity (Richards et al., 1995) might be necessary for offering alternatives for carcass decontamination.

6 Decontamination treatments: other interventions

TSP is a non-acid compound commonly used for carcass decontamination, and applications including TSP were patented for poultry decontamination (Bender and Brotsky, 1992). Dickson et al. (1994) obtained reductions of *S. Typhimurium*, *L. monocytogenes* and *E. coli* O157:H7 ranging from ca. 0.8 to 1.2 log₁₀/cm² by spraying TSP solutions (55°C) on lean beef muscle. On adipose tissue the reductions ranged from 1.2 to 2.5 log₁₀/cm². TSP concentration was not a significant factor in bacterial reduction by this chemical and, in general, greater reductions were observed when the temperature of the TSP solution was increased from 25 to 55°C. It is likely that the high pH of the TSP solution (ca. 13) was responsible for the bacterial reductions reported by Dickson et al. (1994). Antimicrobial effect of high-pH solutions on foodborne bacterial pathogens has been reported, and is apparently due to membrane disruption of the cells and an increase in the water solubility of the DNA at high pH (Mendonca et al., 1994).

The effectiveness of bacteriocins in beef decontamination was also evaluated. Cutter and Siragusa (1994b) applied nisin solution (5000 activity units/ml) to beef carcass tissue inoculated with various Gram-positive bacteria. Reductions in counts produced by this treatment ranged from 1.79 to 3.54 log₁₀/cm². Cutter and Siragusa (1996) enhanced the inhibition of *B. thermosphacta* on beef surfaces by immobilizing nisin in calcium alginate gels. Using this approach produced greater bacterial reductions on the beef immediately after treatment, and counts remained lower than those of beef treated with nisin during refrigerated storage for 7 d. After storage, the numbers of *B. thermosphacta* on the beef surfaces were 7.1 log₁₀ CFU/cm² for controls, 6.45 CFU/cm² for beef treated with calcium alginate only, 5.26 CFU/cm² for beef treated with nisin only and 2.37 CFU/cm² for beef treated with alginate-immobilized nisin. Other bacteriocins have also been used for controlling pathogens on meat (Goff et al., 1996).

Additional chemicals have been investigated for use as carcass sanitizers. Cutter and Dorsa (1995) found chlorine dioxide at concentrations of up to 20 ppm to be no more effective than regular water in reducing bacteria of faecal origin on beef carcass tissue. Anderson et al. (1977) reported no differences in bacterial reductions on meat after spraying tap water or water added with 200 ppm sodium hypochlorite, but Kotula et al. (1974) found lower bacterial counts on beef carcasses treated with 200 ppm sodium hypochlorite compared to untreated carcasses. In addition, they reported some continued effect of chlorine during storage of the carcasses. Since treatment of carcasses with non-chlorinated water was not included in their study, the reported effect of chlorinated water on bacterial counts may have involved both washing effect and an extended antimicrobial effect. After inoculating different pathogenic and non-pathogenic organisms onto lean and adipose beef tissue, Dickson (1988) applied washes with phosphate buffer, ethanol, sodium chloride, sodium hydroxide and potassium hydroxide. Phosphate buffer, ethanol and sodium chloride produced reductions of <1 log, while sodium and potassium hydroxide reduced the populations of inoculated bacteria by as much as 4 logs, with greater reductions in bacterial counts on adipose tissue than on lean tissue. Castillo et al. (1998d) observed reductions in *E. coli* O157:H7 and *S. Typhimurium* counts on beef carcass surfaces after the application of acidified sodium chlorite (ASC) solutions. When phosphoric acid was used to acidify sodium chlorite, the resulting ASC solution reduced populations of both pathogens by 3.8 to 3.9 log cycles, while when ASC solutions were prepared by acidifying with citric acid, the reductions obtained ranged from 4.5 to 4.6 log cycles. Bromine-containing compounds have also been shown to reduce microbial

populations on beef carcasses, with Kalchayanand et al. (2009) reporting reductions in APC and Enterobacteriaceae populations up to 3.6 logs, similar to hot water washing.

Steam treatments of beef or sheep carcasses were attempted by various investigators with little success (Anderson et al., 1979; Dorsa et al., 1996a). Dorsa (1997) reviewed studies that led to the development of a steam pasteurization treatment, and in the late 1990s the process gained rapid popularity among meat processors (Wilson and Leising, 1994). Phebus et al. (1997) assembled an experimental steam pasteurization chamber, and reported reduced counts of *E. coli* O157:H7, *S. Typhimurium* and *L. monocytogenes* by 3.4 to 3.7 log cycles on surfaces of freshly slaughtered beef. However, steam pasteurization alone was not found to achieve greater reductions than other treatments such as knife trimming or steam vacuuming. Nutsch et al. (1997) conducted commercial evaluations of the steam pasteurization process in a beef processing plant in which carcasses were subjected to a preliminary water wash before passing through air blowers to eliminate excessive carcass surface humidity that would favour steam condensation. The carcasses then passed through a steam chamber followed by another section of the cabinet where cold water was applied. Applying this treatment, carcass APCs were reduced from 2.12–2.19 log₁₀ CFU/cm² to 0.56–0.84 log₁₀ CFU/cm². Counts of *E. coli* were also reduced from original counts of 0.60–1.53 log₁₀ CFU/cm² to undetectable levels after steam treatment.

Chemical dehairing could have potential benefits for reducing contamination on meat carcasses. This process was developed by Bowling and Clayton (1992) based on the hair removal process used in the tanning of leather. Schnell et al. (1995) adapted the chemical dehairing process to slaughter operations in a commercial facility. These authors found no differences in APCs or coliform counts in samples from carcasses of dehaired cattle and those of conventionally slaughtered cattle. They concluded that dehairing enhanced the visual cleanliness of the carcasses but was not able to effectively reduce bacterial counts. This report did not include any determination of the extent to which bacterial counts were reduced on the hides of the slaughtered cattle by the dehairing process; therefore, the impact of this treatment on the prevention of faecal contamination from the hides to the carcass surfaces could not be determined. Adapting the chemical dehairing process to laboratory testing, Castillo et al. (1998c) found reductions in *E. coli* O157:H7, *S. Typhimurium*, *E. coli*, coliforms and APCs on artificially contaminated bovine skin, ranging from 3.4 to >4.8 log₁₀/cm². The authors concluded that dehairing had commercial potential in controlling contamination during dehiding operations. More recently, Nou et al. (2003) evaluated dehairing of cattle hides in a commercial beef processing facility and concluded that hide-to-carcass contamination with pathogens was reduced.

Other agents such as ozonated water or hydrogen peroxide were also evaluated, with variable results when compared to treatments such as trimming or washing (Gorman et al., 1995b; Reagan et al., 1996). Meat irradiation was recently approved for decontamination of fresh frozen meat, and it was previously approved for treating poultry and pork. Many reports indicate that this process is quite effective for reducing pathogenic contamination from ground beef and poultry carcasses (Clavero et al., 1994; Lee et al., 1996; Tarté et al., 1996). A multiple hurdle approach, or use of sequential process interventions, might be necessary for reducing contamination with pathogens (Arthur et al., 2004; Castillo et al., 1998b; Phebus et al., 1997). Investigations were conducted on combinations of carcass decontamination procedures to determine possible levels of pathogen reduction during meat processing. Reported success is variable and sometimes contradictory. For example, in reviewing treatments at four beef packing plants, it was reported that spraying

carcasses with 2% lactic acid, steam-vacuum or trimming was ineffective, and that using only steam or hot water treatments without the other treatments substantially reduced bacterial contamination (Gill and Landers, 2003). Gill and Badoni (2004) compared 0.02% peroxyacetic acid, acidified 0.16% sodium chlorite, 2% lactic acid and 4% lactic acid on chilled beef surfaces. They found that a negligible reduction of coliforms or *E. coli* resulted from exposure to peroxyacetic acid and ASC, and that both were less effective than 4% lactic acid. They surmised that varied results in evaluating antimicrobial treatments might be due to their application on different types of meat surfaces, and that the meat surface microflora likely reflects the effect of prior antimicrobial treatments. In addition, peroxyacetic acid concentrations up to 600 ppm were reported to be ineffective antimicrobial treatments when applied to chilled beef carcass surfaces that were inoculated (King et al., 2005).

Irradiation of carcasses to reduce or eliminate *E. coli* O157:H7 on beef surfaces was investigated by Arthur et al. (2005) and Maxim et al. (2014). Arthur et al. (2005) subjected beef surfaces to E-beam irradiation at 1 kGy and reported a 4-log/cm² reduction. The authors concluded that chilled carcasses could be irradiated to reduce surface contamination without affecting flavour or aroma of subsequently produced ground beef. Using a different approach, Maxim et al. (2014) developed a chamber designed to obtain uniform E-beam dose distribution on the surface of a carcass to obtain a more reliable and controlled treatment. The 'Maxim Chamber' was tested on rabbit carcasses and successfully obtained an even distribution of dose, providing a >5-log reduction of *E. coli* O157:H7.

Many approaches to decontaminate meat surfaces were investigated and implemented; however, none of the approved interventions is capable of eliminating the presence of pathogens. In an attempt to reduce risk, it is common for meat processors to apply several redundant pathogen reduction technologies, but elimination of bacterial contamination cannot be guaranteed (Barkocy-Gallagher et al., 2003; Elder et al., 2000). Proper handling of meat products by end users is still required to assure safety.

7 Processing operations: fabrication

Many beef carcasses are chilled for at least 18 hours prior to fabricating them into smaller portions. Although contamination during chilling is rarely addressed, it is certainly possible. Potential sources of contamination include direct contact by employees, contact between individual carcasses or environmental contamination by either air, water or physical contaminants, such as rail dust. Since the beef carcasses were processed to minimize contamination during the slaughter process, it is imperative to maintain hygienic conditions during further processing of these carcasses.

Fabrication is the process of breaking down the carcass into smaller and smaller portions. The process of fabrication is typically considered to begin when the carcasses exit the chillers. Although all components of fabrication are important, bacterial control can be categorized within four general areas:

- a General hygienic practices
- b Equipment sanitation
- c Environmental controls
- d Interventions

To assure the safety and quality of fresh beef, all of these categories must be effectively managed to reduce further contamination as well as minimize the growth of the existing microbial contamination.

General hygienic practices, often referred to as good manufacturing practices (GMPs) or good hygienic practices (GHPs), are the fundamental programmes required to produce safe and wholesome food. These may include personal hygiene, control of foreign materials (glass, metal, etc.), pest control and building maintenance. There are many sources of information on these types of programmes, including but not limited to the British Standards Institute PAS 220:2008, ISO/TS 22002-1:2009 and the Codex Alimentarius report entitled 'Guidelines for the Control of Nontyphoidal *Salmonella* spp. in Beef and Pork Meat' (<http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=http://ps%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCAC%2BGL%2B87-2016%252FCXG%2B087e.pdf>). The important part of GMPs/GHPs is that they all strive to avoid unnecessary contamination. While contamination in and of itself is unavoidable, a significant amount of contamination can be minimized or eliminated by these practices. Processors will implement these programmes to various degrees, depending on the physical structure of the establishment and the geographic location, but every processor can use these programmes to instil a sense in all of their employees that they are not manufacturing random industrial items, but are in fact producing food which will be consumed by families like theirs.

Sanitation is usually thought of as a prerequisite programme, much like the GMPs/GHPs. However, the significance of sanitation, especially equipment sanitation, to the production of safe and wholesome beef cannot be overstated. Consider the results of poor sanitation. Meat residue remains on the equipment at temperatures conducive to rapid growth of microorganisms. The entire microbiome, including spoilage and pathogenic bacteria, reach high populations within a relatively short time. When production begins again, this meat residue with high microbial populations becomes an inoculum for all of the fresh meat with lower populations of bacteria. Improper sanitation contributes to both food safety and shelf life issue.

There are a variety of approaches to sanitize beef processing establishment, but all follow the same basic outline. The initial step is a 'dry' clean up, intended to remove large particles of meat residue and other miscellaneous soil from the equipment. This dry clean up is important, it reduces the amount of labour required later in the sanitation process, and also reduces the amount of sanitation chemicals required. Sanitation chemicals contribute to operational costs in two ways. First, there is the initial purchase of the chemical, and excessive chemical use requires more chemicals to be purchased. The second cost is often poorly understood, even by management. All of the sanitation chemicals go down the drain. Wastewater requires treatment, and excessive chemical use can contribute to increased waste treatment costs. Of equal importance, these waste chemicals enter the environment, and at some point may require additional treatment, if the waste is discharged into a water system which is used for drinking water by a community downstream. Minimizing chemical usage, within the boundaries of effective use, is both financially and environmentally responsible.

The second common step in equipment sanitation is a water rinse. In many cases, the water will be warmed to facilitate the removal of fat from the surfaces. However, the temperature should be below 57°C, 135°F, to avoid coagulating the meat protein on to the equipment surface. After rinsing, the cleaning chemicals are applied with some type of mechanical force (manual scrubbing, pressure wash). The commonly used cleaning

chemicals are generally alkaline to facilitate the removal of lipids and proteins. The cleaning chemicals are then rinsed and the surface inspected for visual residue. The inspection step is extremely important, in that residual meat cannot be adequately sanitized, and residual cleaning chemicals will often neutralize sanitation chemicals.

The final step is sanitizing, which can be accomplished in a variety of physical or chemical methods. Hot water is a commonly used sanitizer, but as with any thermal process requires both an adequate temperature and a sufficient contact time to accomplish the intended purpose. Chemical sanitizers are widely used, with the most common being chlorine-based chemicals. Daily sanitation is essential, and additional sanitation steps may be required when the establishment may not have been operated for several days (national holidays, seasonal events, etc.).

Environmental controls may also be considered part of the GMP/GHP programme. The most common environmental control beyond sanitation is the temperature of the fabrication room. In the United States, the USDA-FSIS permits continuous operations over two shifts (nominally 16 hours) without a full sanitation programme if the room temperature is maintained below 10°C. The rationale for this is that most of the pathogens of concern, notably non-Typhoidal salmonellae, grow slowly or not at all below 10°C. By maintaining the room below this temperature, along with having the carcass typically chilled to less than 5°C prior to processing, the potential growth of non-Typhoidal salmonellae was effectively controlled. While the focus of this environmental control is primarily food safety, it also has the potential to impact spoilage and shelf life. Environmental control is one of the tools commonly used to extend the shelf life of fresh beef, especially for export purposes. As with any GMP/GHP, all of the individual components must work together to achieve the goal.

As food safety has become a larger concern for the beef industry, interventions similar to those included during the slaughter are becoming more common on the fabrication side. Peroxyacetic acid or ASC are commonly applied to subprimal cuts prior to fabrication to retail cuts (Kalchayanand et al., 2012; Liao et al., 2015; Ransom et al., 2003).

8 Packaging, storage and shelf life

8.1 Packaging

After the beef carcasses are cut into smaller portions, they are usually packaged in some form prior to entering commerce. The packaging depends upon the type and size of the cut, such as primals, being shipped for further cutting compared to pre-packaged product that is retail ready, and the intended use. The intended use may be as diverse as delivery to a local restaurant or retailer, or placing in a refrigerated container for international shipment. All of these factors are involved in the selection of the packaging method, and may be employed simultaneously on meat from the same lot of cattle.

Packaging serves two purposes. It protects the meat from further contamination, and also may serve as an environmental control for bacteria. The most widely used method of environmental control by packaging is vacuum packaging. Vacuum packaging simply removes the majority of the oxygen from the package, slowing the growth of bacteria. Many members of the spoilage microbiome are facultatively anaerobic, capable of growing with or without oxygen. However, in many cases anaerobic metabolism is much

less efficient than aerobic metabolism, and the same bacteria simply have a slower growth rate in the absence of oxygen. Vacuum packaging is also dependent upon the packaging film, as using a film with a high oxygen transmission rate will negate the benefit of vacuum packaging.

A variation of vacuum packaging is modified atmosphere packaging. In this case, after a vacuum is pulled to remove the oxygen, the package is back-flushed with a gas mixture. Back-flushing with an oxygen-free gas removes the very small amount of residual oxygen left by the vacuum, and therefore results in an environment with even less residual oxygen. The gas may be an inert gas such as nitrogen or carbon dioxide, or may be a mixture of several gasses. Carbon monoxide was added in a small percentage to the gas, because it helps to maintain the colour of the meat pigment.

Some works documented the inclusion of antimicrobials in the package itself or incorporated into the packaging film. Much of this research has been conducted with processed meats, primarily to address concerns with *L. monocytogenes*. The antimicrobials typically are organic acids, or the salts of organic acids, or natural plant-derived materials. Although they have been shown to be effective, in many cases they are not permitted to be used with fresh beef. These compounds, in this specific application, are considered additives and must therefore be listed on the label. In the United States, the standard of identity for fresh beef prohibits additives, and the products could not be labelled as fresh beef. Many other regulatory restrictions exist, both within and between different countries, and so at this time these additives are not employed to improve the safety and shelf life of fresh beef.

8.2 Storage and shelf life

The factors which influence shelf life are no different from the environmental factors previously discussed. The primary environmental factor is temperature, as at this point the beef should be packaged in a way to prevent further contamination. In 2014, EFSA published a detailed report on the importance of maintenance of the cold chain during storage and distribution. This document is perhaps the most recent and comprehensive review of the subject, and certainly a valuable reference. Their conclusions included:

- a Carcass surface temperature is a more relevant indicator of the effect of chilling on bacterial growth than core temperature.
- b If there is equivalent or less bacterial growth, there is no additional risk for the consumer. Total bacterial growth is affected by the continuum of chilling in the slaughter plant, during transport, deboning, storage, retail and catering/domestic refrigeration.
- c It is possible to have different combinations of slaughterhouse–transportation time–temperature chilling scenarios that result in equivalent or less bacterial growth than those obtained using the currently mandated chilling requirements (chilling to a core temperature of 7°C in the slaughterhouse chillers before transportation for a maximum of 48 hours).

While these recommendations are specific to the European Union, the fundamental principles of bacteriology do not differ throughout the world, and so the same principles are applicable to all fresh beef.

9 Conclusions

Many programmes and processes contribute to the safety and quality of fresh beef. These programmes overlap, so that a partial failure in one does not lead to an overall processing failure. The concept was best described by Leistner (2000) as the 'hurdle' concept, where multiple interventions were applied so that ultimately the majority of the pathogenic microorganisms would be eliminated. Although the hurdle concept was originally applied to pathogenic bacteria, the same concept applies to spoilage bacteria as well. Ultimately, the safety and quality of fresh beef re-lives on an integrated system which starts with the production of healthy live cattle, free of chemical residues and ends with the presentation of the beef to the consumer, ready to eat.

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