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Review article
Ανασκόπηση

Carcass decontamination methods in slaughterhouses: a review

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Μέθοδοι εξυγίανσης σφάγιων σε σφαγεία: ανασκόπηση

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ABSTRACT. European Union legislation approach to meat safety assurance advocates use of strict preventive hygiene measures and procedures to overcome threats by pathogens. Therefore, there is no need for carcass decontamination at the last stage of slaughtering process, using intervention methods. In contrast, the United States permit and regulate intervention decontamination methods. Generally, a HACCP system may use intervention treatments. These may be based solely on a non-intervention system or use a combination of both. Interventions have the advantage of achieving a consistent reduction in bacterial contamination and require less manual input, but on the other hand, may also lead to carcass discolouration, produce large quantities of waste water and be relatively expensive. Moreover, intervention methods could constitute a means of concealing poor hygiene conditions during slaughtering or, even more, their residues could be a potential hazard for food safety. Non-intervention systems have the advantages of being relatively inexpensive, easy to implement and more preventive. However, these systems rely heavily on human effort and the possibility for error is considerably higher than the intervention systems. There are many carcass decontamination methods, as described in the relevant literature and used in slaughterhouses worldwide, such as: (i) cold/warm water washing, (ii) hot water washing, (iii) steam vacuuming, (iv) steam pasteurization, (v) irradiation, (vi) organic acid application, (vii) combination of organic acid application with other decontamination treatments and (viii) other chemical treatments. Aim of this review is to provide information on the relevant literature, as well as describe and comment on the questions raised.

Keywords: carcass decontamination, intervention and non-intervention methods, slaughterhouse hygiene

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ΠΕΡΙΛΗΨΗ. Η νομοθεσία της Ευρωπαϊκής Ένωσης για την ασφάλεια του κρέατος προβλέπει την εφαρμογή ιδιαίτερα αυστηρών προληπτικών μέτρων υγιεινής και διαδικασιών, με στόχο την πρόληψη των κινδύνων. Επομένως, δεν είναι απαραίτητη η χρήση παρεμβατικών τεχνικών εξυγίανσης στο τέλος της παραγωγικής διαδικασίας. Αντίθετα, οι Ηνωμένες Πολιτείες επιτρέπουν και έχουν ρυθμίσει στη νομοθεσία τους τη χρήση παρεμβατικών τεχνικών εξυγίανσης των σφάγιων. Γενικότερα, ένα σύστημα HACCP μπορεί να βασίζεται σε παρεμβατικές τεχνικές εξυγίανσης, να χρησιμοποιεί μη παρεμβατικές μεθόδους ή να συνδυάζει και τα δύο. Η χρήση παρεμβατικών τεχνικών είναι πιο δαπανηρή, αποχρωματίζει τα σφάγια και παράγει μεγάλες ποσότητες αποβλήτων. Επιπλέον, οι μέθοδοι αυτές μπορεί να αποτελέσουν παράγοντα απόκρυψης της κακής υγιεινής της παραγωγικής διαδικασίας ή να έχουν επιπτώσεις στην ασφάλεια του κρέατος, εξαιτίας της υπολειμματικής δράσης ορισμένων ουσιών που χρησιμοποιούνται. Αντιθέτως, οι μη παρεμβατικές τεχνικές είναι πιο φθηνές, πιο εύκολες στην εφαρμογή και αντιμετωπίζουν την αιτία της επιμόλυνσης αυτής καθ' αυτής, ως μια προληπτική διαδικασία. Βέβαια, οι μη παρεμβατικές τεχνικές στηρίζονται σε μεγάλο βαθμό στον ανθρώπινο παράγοντα, απαιτούν συνεχή παρακολούθηση και προσπάθεια και δεν αποκλείουν την πιθανότητα αστοχίας στις διαδικασίες. Στη διεθνή βιβλιογραφία περιγράφονται και χρησιμοποιούνται στην πράξη διάφορες τεχνικές εξυγίανσης σφάγιων, όπως: (α) πλύσιμο με ψυχρό ή χλιαρό νερό, (β) πλύσιμο με θερμό νερό, (γ) αναρρόφηση σε συνδυασμό με ατμό, (δ) αποστείρωση με ατμό, (ε) εφαρμογή ακτινοβολίας, (ζ) εφαρμογή διαλυμάτων οργανικών οξέων, (η) συνδυασμός εφαρμογής διαλυμάτων οργανικών οξέων με άλλες μεθόδους εξυγίανσης και (θ) άλλες τεχνικές χημικής εξυγίανσης. Σκοπός της παρούσας ανασκόπησης είναι η παρουσίαση της σχετικής διεθνούς βιβλιογραφίας και ο σχολιασμός ερωτημάτων σχετικών με τις τεχνικές εξυγίανσης σφάγιων.

Λέξεις ευρετηρίασης: εξυγίανση σφάγιων, παρεμβατικές και μη-παρεμβατικές μέθοδοι, υγιεινή σφαγείων

INTRODUCTION

Most food industry sectors and especially meat sector face a major and continuing challenge in trying to limit the extent to which food products become contaminated with pathogenic bacteria, involved in food borne diseases (Sheridan, 1998; Norrung and Buncic, 2008). In recent years, meat industry and regulatory authorities have attempted to limit the presence of pathogens on carcasses by the application of Hazard Analysis and Critical Control Points (HACCP) systems within meat processing plants and slaughterhouses. These are designed to assist in the management and control of the slaughtering process, as well as meat processing, by identifying the critical control points where contamination can occur and specifying preventive actions that can be taken (Trianti et al., 2008; Tsola et al., 2008; Mataragas et al., 2012; Milios et al., 2013). However, HACCP systems though aiming at reducing pathogens to acceptable levels, as currently defined with Food Safety Objectives, do not eliminate the possibility of their presence.

In slaughterhouses, minimization of microbial contamination on carcasses is important during processing, in order to delay spoilage of meat and to protect public health. However, microbial contamination of carcasses is inevitable while converting live animals to meat. Internal muscles of healthy animals are generally sterile at the time of slaughter, but, under normal processing conditions, equipment and workers could spread bacteria to newly exposed meat surfaces throughout processing (Kang et al., 2001).

There are two basic approaches for food safety assurance during slaughtering procedures worldwide: the EU and the USA legislation approaches. The EU approach puts forward use of strict preventive hygiene measures and procedures to overcome threats by pathogens. Therefore, there is no need for carcass decontamination at the last stage of slaughtering process using intervention methods (Bolton et al., 2001). Moreover, very recently, some intervention methods such as the application of organic acids were permitted in the EU. Until now, these were perceived to be a means of concealing poor hygiene during slaughter or their residues were thought to be a potential hazard for food safety. On the other hand, the USA approach exists, whereby intervention decontamination methods are permitted and regulated by legislation (Anon., 1996). It should be underlined, however, that recently, a Commission Regulation approving the use of lactic acid to reduce surface contamination on bovine carcases has been issued (Anon., 2013).

This article aims at enriching the limited relevant Greek literature with information concerning the implication of carcass decontamination methods, useful for those involved in veterinary administrations, at various levels, as well as the meat producing industry, and, in general, the overall animal production, in a subject of interest for the public.

MEAT SAFETY MANAGEMENT IN SLAUGHTERHOUSES – THE EU APPROACH

EU legislation covering meat safety assurance relatively to slaughterhouse operation is very strict and thorough. A number of Regulations, e.g. 852/2004, 853/2004, 854/2004, 2073/2005, 1441/2007 (Anon., 2004a; 2004b; 2004c; 2005; 2007) set the rules for proper Good Hygiene Practice (GHP) and Good Manufacturing Practice (GMP) in slaughterhouses, HACCP implementation, official veterinary ante- and post-mortem inspection and determine specific microbiological criteria for hygiene verification. Indicatively, it must be mentioned that EU legislation regulates sampling frequency for hygiene indicator organisms from carcass surface during hygiene verification. According to EU perspective, the adoption of strict preventive hygiene measures and procedures is sufficient to assure that pathogens are kept under control and, therefore, there is no need for the use of decontamination methods (Bolton et al., 2001). These authors suggested use of a non-intervention HACCP system in order to adopt the EU approach of meat safety. This HACCP system includes four critical control points, namely (i) dehiding, (ii) evisceration, (iii) removal of the spinal cord and (iv) chilling. Operations taking place during dehiding can lead to contamination of the carcass. Therefore, the procedure should be closely monitored. Furthermore, Sheridan (1998) suggests that state of the live animal is a major critical control point in any HACCP programme for meat processing continuum. The physiological state of the animal and internal and external microbial loading are all important determinants of the final microbiological quality of derived meat, as it is proved that, dressing could be a significant contamination stage (Hudson et al., 1998; Reid et al., 2002; Byrne et al., 2007).

According to EU Regulation 854/2004 (Anon., 2004c), official veterinarians have to verify compliance with the food business operator's duty to ensure that animals that have bad hide, skin or fleece conditions and therefore, there is an unacceptable risk of contamination of meat during slaughter, are not slaughtered for human consumption unless they are cleaned beforehand. Byrne et al. (2007) suggested that animals, sheep in particular, presented for slaughter should be divided into two categories: (i) clean sheep which may be slaughtered without additional measures and (ii) dirty sheep requiring additional measures. They also proposed specific measures, e.g., (i) slaughter of the high risk animals at the end of the day, (iib) reduced line speed, (iii) thorough cleaning of operators hands, arms and aprons before and during the pelt removal process, (iv) use of an inverted dressing procedure, (v) greater spacing between carcasses and, in some cases, (vi) rejection of carcasses. These are non-intervention measures aiming at meat safety and, therefore, consistent with EU legislation approach.

Furthermore, appreciable research has been made on the contribution and significance of pre-harvest reduction of bacteria in live animals (Callaway et al., 2004; 2013; Oliver et al., 2009). Because of the potential improvement in overall food safety that pre-harvest intervention strategies can provide, a broad range of pre-slaughter intervention strategies are under investigation. Potential interventions include direct anti-pathogen strategies, competitive enhancement strategies and animal management strategies. Included in these strategies are: competitive exclusion, probiotics, prebiotics, antibiotics, antibacterial proteins, vaccination, bacteriophage, diet, and water trough interventions (Cray and Moon, 1995; Faith et al., 1996; Galland et al., 2001; Schrezenmeir and de Vrese, 2001; Smith et al., 2001; Crump et al., 2002; Daniels et al., 2003, LeJeune et al., 2004; Sargeant et al., 2004; Davis et al., 2005; Mora et al., 2005; Wetzel and LeJeune, 2006; Woerner et al., 2006; Sheng et al., 2006). The parallel and simultaneous application of one or more pre-slaughter strategies has the potential to synergistically reduce the incidence of human food-borne diseases by erecting multiple hurdles, thus preventing entry of pathogens into the food chain (Callaway et al., 2004). However, development of pre-harvest strategies does not eliminate a need for good hygiene and procedures in the processing plant and food preparation environment. Instead, live-animal interventions to reduce pathogens must be installed in a multiple-hurdle approach that complements in-plant interventions, so reduction in pathogen entry to the food supply can be maximized (Callaway et al., 2013).

A scientific issue risen recently, has been whether pre slaughter washing of dirty animals may help reduce the overall prevalence of bacteria on carcasses. Pre slaughter washing is an intervention measure, but could be consistent with EU legislation approach. According to Byrne et al. (2007), level of bacteria found on dirty and dry sheep were higher than the level found on dirty and wet sheep. Therefore, pre slaughter washing of dirty sheep may help reduce the prevalence of bacteria (Byrne et al., 2000). On the other hand, other studies have suggested that washing may not be helpful (Ellerbroek et al., 1993; Biss and Hathaway 1996). Furthermore, shear or/and depilation do not affect microbial load (Schnell et al., 1995). Evisceration could be another critical control point in a non-intervention HACCP system. If the rectum is nicked or faecal material leaks from the anus, the rump area of the carcass may be contaminated (Gill, 1995). Robbing, bagging, tying of the bung and sterilization of the equipment used could be preventive measures (Bolton et al., 2001). The third critical control point for a non-intervention HACCP system is, according to the authors' opinion, the Specified Risk Material removal from the ruminants. Removal and incineration of these materials are regulated by separate EU legislation, i.e. Regulations 1069/2009 and 142/2011 (Anon., 2009; 2011). Finally, chilling is the last critical control point as it constitutes a stage where bacterial growth is prevented. A non-intervention system, similar to that described above, has been successfully applied to pork slaughter in the USA (Bolton et al., 1999), where carcass contamination levels decreased from 8% to 1.5%.

On the other hand, trimming is an intervention measure consistent with EU legislation approach. USA has also adopted a zero tolerance policy for visible contamination on carcasses' surface (Anon., 1996). Zero tolerance means that every carcass must be free of faeces, ingesta and milk (in the case of cows). Each carcass should be thoroughly inspected and any contamination found is removed by trimming using a sterilized knife. Trimming significantly reduces carcass' contamination (Kochevar et al., 1997).

We wish to add at this point that, very recently, a Commission Regulation approving use of lactic acid to reduce surface contamination on bovine carcases has been issued (Anon., 2013). The European Food Safety Authority (EFSA) adopted a scientific opinion on the evaluation of the safety and efficacy of lactic acid for the removal of microbial surface contamination from beef carcases, cuts and trimmings. In view of that opinion, taking into account that lactic acid can provide a significant reduction of possible microbiological contamination, it is appropriate to consider its use as a means of reducing surface contamination. Such use should be subjected to certain conditions. In particular, lactic acid should only be applied either by spraying or misting using a 2% to 5% solution in potable water at temperatures of up to a maximum of 55 °C. Finally, its application should be limited to use on carcases, half carcases or quarters at the slaughterhouse and it should be integrated into good hygienic practices and HACCP-based systems.

MEAT SAFETY MANAGEMENT IN SLAUGHTERHOUSES – THE USA APPROACH

The USA legislation permits and regulates intervention decontamination techniques. In 1996, the US Department of Agriculture/Food Safety and Inspection Service (USDA/FSIS) established requirements designed to reduce the occurrence and levels of pathogenic organisms on meat and poultry products by implementing HACCP as the principal food safety programme (Anon., 1996). In 2002, FSIS required all beef processors to determine whether *Escherichia coli* O157:H7 contamination was a hazard likely to occur in their process and, if so, to address this hazard in the HACCP plan. The reassessment effectively resulted in all beef slaughter facilities to implementing at least one carcass intervention treatment to reduce hazard at an acceptable level (Algino et al., 2007).

There are several acceptable interventions for reducing carcass contamination approved by FSIS that can be used without prior agency approval (Anon., 1996). These are (i) steam-vacuum systems that utilize steam only, or water and steam, (ii) pre-evisceration rinse systems consisting of a rinse and a second rinse with an organic acid solution, (iii) chlorinated water washes of 20 to 50 ppm, (iv) food-grade organic acids sprays of 1,5% to 2,5 % (v) food-grade trisodium phosphate sprays of 8% to 12% at 32 to 44 ^{o}C and not exceeding 30 s, (vi) hot water sprays at >74 ^{o}C for 10 s and (vii) steam pasteurization systems (Dorsa, 1997).

CARCASS DECONTAMINATION METHODS IN SLAUGHTERHOUSES

Physical decontamination treatments

Cold/warm water washing

There are many carcass decontamination methods described in the relevant literature and used in slaughterhouses worldwide. Carcass rinse with water before evisceration or after hide removal has been suggested to decrease the carcass surface's microbial load by reducing the bacteria's ability to attach on meat surface (Dickson, 1994). Furthermore, washing at the end of the slaughtering process and before chilling, is used as a decontamination method (Hugas and Tsigarida, 2008; Gill, 2009). Under commercial conditions, cold and warm water spraying using wash cabinets reduced aerobic bacteria, coliforms and *E. coli* on beef carcasses by 0.5-1.0 orders of magnitude (Reagan et al., 1996; Gill and Landers, 2003). Carcasses are washed with cold (10-15 ^{o}C) or warm (15-40 ^{o}C) potable water to remove bone dust and blood clots (Bolton et al., 2001). A number of investigations, on the effect of spraying beef carcasses with cold or warm water have shown that decontamination does not occur (Gill et al., 1996a; McEvoy et al., 1999) or it is statistically insignificant (Yalcin et al., 2004), while in other studies, it has been recorded that there are significant reductions only at specific carcass sites (Jericho et al., 1995), as, in many cases, washing simply redistributed bacteria from one area to another (Jericho et al., 1996, Gill et al., 1996b, McEvoy et al., 1999). McEnvoy et al. (2003) concluded that warm water washing can lead to increase of contamination, because of bacterial redistribution and, therefore, water spray direction, temperature and pressure are critical factors that should be taken under consideration. According to Reagan et al. (1996) use of cold or warm water is less effective than hot water as it only removes bact eria, while hot water application leads to their injury or death. Therefore, washing with cold or warm water is not considered to be a decontamination step as its effects are related solely to improving carcass appearance and not food safety (Bolton et al., 2001).

Hot water washing

Water at 75 to 85 ^{o}C may be applied for 9 to 12 s to the carcass under pressure (9.7-13 Pa) as a spray or using a deluge system which delivers sheets of water at 85 ^{o}C for 10 s onto the carcass (Gill and McGinnis, 1999; Bacon et al., 2000). Numerous studies have shown the ability of hot water washing to reduce bacterial contamination of beef carcass tissue (Dorsa et al., 1996; Dorsa, 1997; Kalchayanand et al., 2009). Furthermore, Gill and Baker (1998) have reported that sheep carcass washing at the end of the slaughtering process resulted in a microbial population reduction of 0.5 log, while Ellerbroek et al. (1993) quoted that the microbial load of sheep carcass surface was reduced by half. Finally, Dorsa et al. (1996) suggested that the combination of hot water at the temperature of 70 °C and with low pressure (1.36 atm) and warm water application (30 °C) with high pressure show the best results. Hot water is easier and more economical to generate than steam. However, a lot of water is wasted and heat may discolour cut surfaces of the carcasses (Bolton et al., 2001).

Recently, a new argument has arisen concerning use of recycled water as a decontamination technique. For carcass decontamination purposes, only use of potable water is currently allowed in the EU. However, in 2010 a Scientific Opinion on the safety and efficacy of using recycled hot water as a decontamination technique for carcasses was issued by EFSA Scientific Panel on Biological Hazards and Contaminants in the Food Chain (EFSA, 2010). According to this, decontamination efficacy of recycled hot water does not differ significantly from that of hot potable water. With recycled hot water, only microbiological risks associated with heat-resistant bacterial spores (*Clostridium botulinum, Cl. perfringens, Cl. difficile*, *Bacillus cereus)* are relevant. These risks can be controlled through ensuring that recycled hot water is verifiably subjected to such reheating and frequency of renewal regimes which ensure that the microbiological risk in recycled water is not higher than in hot potable water.

Steam vacuuming

Steam vacuuming cleaning is increasingly used to remove visible contaminants from carcasses, especially in the USA and Canada (Gill, 2009; Loretz, 2011). Steam vacuum systems use hot water, steam and vacuum to decontaminate small areas on the carcasses. The water agitates slightly the surface of the carcass at 85 °C, killing and removing bacteria. Steam continually sanitises the hand-held unit and boosts water temperature while vacuum removes the wastewater and contaminants (Bolton et al., 2001). Significant decontamination effects have been demonstrated in experiments where small areas of beef carcasses were treated using a steam vacuum (Gill and Bryant, 1997; Kochevar et al., 1997). However a number of problems have been identified, such as (i) inability to completely eliminate faecal pathogens, (ii) temperature of the meat surface may only reach 34-49 °C, (iii) at least 10 s are required, (iv) curvature of some surfaces may make proper contact with the vacuum head difficult, (v) bovine faeces may be redistributed rather than removed and (vi) it is only suitable for decontaminating small areas of the carcass (Bolton et al., 2001).

Steam pasteurization

Steam pasteurization systems carry out a process, in which surface water is initially removed from carcass before steam is applied (temperature inside steam chamber 82-94 °C, application for 6-8 s) to kill pathogens. The carcass surface is then chilled with water (water temperature 4.4 °C, pressure 1.88 atm for 10 s). Steam pasteurization may discolour cut surfaces on beef carcasses (Bolton et al., 2001). Nutsch et al. (1997) reported that application of steam for 1 s on beef carcass surface (which results to an increase of meat temperature up to 90-96 °C), followed by chilling with cold water for 6-8 s leads to similar reduction of bacterial population to that achieved by hot water washing. Dorsa et al (1996) compared a hot water washing at 82.2 °C to steam delivered though a closed cabinet on lamb carcasses. Steam treatment consisted of water wash at 15.6, 54.4 or 82.2 °C and a final cool water rinse (15.6 °C). It was concluded that the moist-heat interventions were effective for reducing microbial population regardless of the application method. Milios et al. (2011) applied steam to lamb carcasses surface, after pluck removal and immediately before chilling, in order to investigate its effect on the hygienic and organoleptic characteristics of meat. Critical limits applied were atmospheric temperature inside steam chamber 90 °C and duration of steam application 8-10 s. Based on the results of this study, it was concluded that Enterobacteriaceae and total viable counts populations were reduced by 1 $\log_{10}$ cfu cm^{-2} and 0.72 $\log_{10}$ cfu cm^{-2}, respectively. Moreover, effects on characteristics of meat were not significant. James et al. (2000) concluded the same when applying steam on lamb carcasses' surface.

Irradiation

Irradiation of food generally uses γ rays or electron beams. Antimicrobial activity of ionizing radiation is due to direct damage of DNA and the effect of generated free radicals. (Loretz, 2011). A 1-kGy dose of electron beam radiation reduced inoculated *E. coli* O157:H7 on beef carcass surface cuts, by at least four orders of magnitude without affecting sensory characteristics (Arthur et al., 2005). Application of irradiation at adequate dosages seems also to be effective, but costs for the infrastructure and the acceptance by the consumers should also be considered (Loretz, 2011).

Chemical decontamination treatments

Organic acid application

Organic acids, such as lactic or acetic acid, are usually applied using a spray cabinet. Organic acids are widely used in USA, but have not been permitted under EU Regulations until now. Lactic acid solution 1% application on beef carcasses at the temperature of 55 °C reduced microbial population to levels similar to that described for decontamination techniques (Siragusa, 1995). Applications of 3% acetic acid solutions were reported to have similar results (Prasai et al., 1991; Cutter and Siragusa, 1994; Hardin et al., 1995; Kenney et al., 1995; Dorsa, 1997). Other researchers claim that there is no clear evidence that organic acid application has a significant lethal effect on its own. Acid kills some cells and damages many others on meat surface, while the carcasses are discoloured and operators may experience skin/eyes irritation when acetic acid is used (Bolton et al., 2001).

Carpenter et al. (2011) conducted a study, in order to assess the decontamination efficacy of various acid solutions' application by comparing spray washing at 55.4 °C with 2% levulinic acid to that with lactic or acetic acid for decontamination of pathogenic bacteria inoculated onto meat surfaces, and their residual protection against subsequent growth of pathogenic bacteria. The model systems included *E. coli* O157:H7 on beef plate, *Salmonella* on chicken skin and pork belly and *Listeria monocytogenes* on turkey roll. In the decontamination studies, acid washes lowered recoverable numbers of pathogens by 0.6 to 1 log, as compared to no-wash controls, and only lactic acid lowered the number of pathogens recovered, as compared to the water wash. Washing with levulinic acid at 68.3 or 76.7 °C did not result in additional decontamination with *E. coli*. Acetic acid prevented residual growth of *E. coli* and *L. monocytogenes* and it reduced numbers of *Salmonella* on chicken skin to below recoverable levels. Overall, levulinic acid did not prove as effective decontamination as lactic acid and not residual protection as acetic acid.

Other chemical treatments

Chemicals, such as acidified sodium chlorite (ASC), clorine, DBDMH (1,3-Dibromo-5,5 dimethylhydantoin), electrolyzed water, H_2O_2, ozone, peroxyacetic acid, saponin, sodium bicarbonate and trisodium phosphate have been evaluated for decontamination of beef carcasses (Loretz, 2010). Furthermore, a lot of research has been carried out on the effectiveness of various commercially available preparations, (Cutter and Siragusa, 1995; Reagan et al., 1996; Bell et al., 1997; Dorsa et al., 1997; Cutter, 1999; Cutter and Rivera-Betancourt, 2000; Cutter et al., 2000; Bosilevac et al., 2004; Gill and Badoni, 2004; King et al., 2005; Algino et al., 2007; Penney et al., 2007; Arthur et al., 2008; Pearce and Bolton, 2008; Kalchayanand et al., 2009).

Trisodium phosphate (10%, 35 °C) proved to be effective and significantly reduced microbiological contamination on inoculated beef carcass surface parts (Cutter et al., 2000). Research by Cabedo et al. (1996) and Gorman et al. (1995; 1997) showed that spray-washing with trisodium phosphate reduced contamination of beef brisket and that it may inhibit bacterial attachment, thereby allowing easier bacterial cell removal by washing. Research by Cutter et al. (2000) showed that spray-washing of beef fat with a solution of cetylpyridinium chloride (1%) immediately reduced inoculum levels of *E. coli* O157:H7 and *Salmonella typhimurium* to virtually undetectable levels. A study by Ransom et al. (2001) yielded similar conclusions. However, residual cetylpyridinium chloride levels following treatment were considered excessive for human consumption. Spraying of beef carcasses with room-temperature acidified (citric acid-activated) sodium chlorite has been shown to substantially reduce numbers of inoculated *E. coli* O157:H7 (Castillo et al., 1999). Acidified sodium chlorite also effectively reduced, to levels close to or below the counting method detection limit, pathogens that were spread to areas beyond the initially contaminated area. However, 22% to 50% of carcasses treated with acidified sodium chlorite still yield countable *E. coli* O157:H7 colonies. This chemical received approval from FSIS - USDA for use in beef carcass decontamination systems. On the other hand, acidified sodium chlorite, electrolyzed water or peroxyacetic acid mainly yielded reductions below one order of magnitude (Algino et al., 2007; Arthur et al., 2008; Gill and Badoni, 2004; King et al., 2005; Penney et al., 2007). Under commercial conditions, H_2O_2 and ozone reduced naturally occurring bacteria on carcasses by 1.0-1.1 and 1.1-1.3 log CFU cm^{-2}, respectively (Reagan et al., 1996; Algino et al., 2007).

Combined decontamination treatments

Combination of physical and chemical treatments

Organic acids, in combination with other treatments, such as hot water washing or chilling, may have a beneficial effect, as demonstrated by several researchers (Dickson and Anderson, 1992; Bolton et al., 2001). Decontamination effect of hot water and organic acid pasteurization on beef was demonstrated under experimental conditions using a model spray cabinet by Castillo et al. (1998). In that study, beef meat was subjected to a high pressure water wash prior to treatment. Critical limits set for hot water washing in combination with organic acid application were (i) high pressure wash at first by hand (0.47 atm) for 90 s and then in a cabinet for 9 s (pressure 1.70-2.72 atm) at the temperature of 35 ^{o}C, (ii) hot water wash water (water temperature 95 ^{o}C, pressure 1.63 atm for 5 s) or (iii) lactic acid solution (2%) application at 55 ^{o}C for 11 s under 1.87 atm).

Carcass washing followed by organic acid application has been proven to be more effective in *E. coli* O157:H7 and *S. typhimurium* population reduction, than trimming or washing separately (Hardin et al., 1995). Furthermore, the combination of hot and warm water washing of beef and sheep carcasses resulted to a significantly higher total bacterial population reduction than use of the intervention treatments separately (Dorsa et al., 1996). Similar reduction was noticed for total coliforms and *E. coli* population, which was even higher when steam was simultaneously applied (Dorsa et al., 1996).

Graves Delmore et al. (1998) evaluated some intervention treatments separately and in sequence for their efficacy, in reducing microbial contamination on beef tissue inoculated with *Escherichia coli.* In particular, they used water washing (21- 54 ^{o}C, 3.4 atm, 5.6 s), rinsing with lactic acid solution (2%, 38-54 ^{o}C, 2.04 atm, 5.6 s), rinsing with water (21-54 ^{o}C, 2.65 atm, 20 s) and, finally, rinsing with lactic acid solution (2%, 38-54 ^{o}C, 2.04 atm, 5.6 s). Treatments reduced the aerobic plate counts and *E. coli* counts of samples inoculated to have 5.0-7.4 log CFU cm^{-2} by 1.1 to 4.3 log. Similarly, most treatments reduced plate counts and total coliform counts of samples inoculated to have 1.8-3.7 log CFU cm^{-2} by 0.1 to 1.7 log. Combinations involving 3 or 4 treatments were more effective in reducing bacterial contamination than single- or two-treatment combinations.

Multiple sequential interventions during slaughter

Bacon et al. (2000) applied multiple-sequential interventions to reduce beef carcass contamination. This study evaluated microbial populations on animal hides and changes in carcass microbial populations at various stages in the slaughtering process. Following slaughtering process, application of multiple-sequential decontamination interventions included steam vacuuming (104-110 °C, 1.36-3.4 atm, negative pressure 7 to 12 mm of Hg), pre-evisceration carcass washing (29-38 °C, 1.9-3.3 atm, 6-8 s), pre-evisceration organic acid solution rinsing (1.6-2.6% lactic acid solution, 43-60 °C, 3.12-3.19 atm, 2-4 s), hot water carcass washing (71-77 °C , 0.68-2.25 atm, 10-14 s), post-evisceration final carcass washing (16-32 °C water, 4.76-8.85 atm, 10-14 s), and post-evisceration organic acid solution rinsing (1.6-2.6% lactic acid solution, 43-60 °C, 3.12-3.19 atm, 2-4 s). The results proved that multiple-sequential interventions reduced beef carcass contamination by 1.3 to 4.4 log and support the concept of using sequential decontamination processes in beef packing plants as a means of improving the microbiological quality of beef carcasses.

Finally, Algino et al. (2007) evaluated effectiveness, as measured by decreases in generic *E. coli*, coliforms, Enterobacteriaceae and aerobic plate counts of intervention treatments used at very small beef slaughtering facilities. The interventions studied were: dry-aging, low-pressure hot-water spray, high-pressure hot-water spray, 2.5% acetic acid spray and spray with a mixture of citric acid, ascorbic acid and erythorbic acid. There were no significant differences between the various treatments and all treatments caused significant reductions in indicator organisms. For all treatments, rapid decreases in cooler temperature and relative humidity significantly affected indicator reduction, and, for hot-water washing, increase of spray time led to significantly greater reductions.

Biological decontamination treatments

Biological interventions such as bacteriophages and bacteriocins show some promise as decontamination treatments (Loretz, 2011). Bacteriophages are increasingly used in the food industry, especially to inactivate *L. monocytogenes* (Greer, 2005). Bacteriophages are generally considered to be safe in application and highly host-specific (Greer, 2005; Hudson et al., 2005). Yet, their use on food commodities is still impaired by factors, such as guarantee of a sufficient threshold level or potential resistance development (Loretz, 2011). For beef carcasses, most available data originate from studies examining beef meat and meat products (Greer, 2005; Bigwood et al., 2008).

Finally, future trends on decontamination technologies include high hydrostatic pressure processing, shockwave technology, high-intensity light, carbon dioxide treatment, ultrasonics, and surface decontamination with electrolyzed water, gas plasma and magnetic fields (Guan and Hoover, 2005).

POULTRY CARCASS DECONTAMINATION TECHNIQUES

A lot of research has been carried out on poultry carcass decontamination techniques, especially because poultry is involved as a risk factor in human campylobacteriosis (Loretz et al., 2010). Physical interventions include water-based treatments, irradiation, ultrasound, air chilling or freezing (Sams and Feria, 1991; Farkas, 1998; Avens et al., 2002; Fabrizioe et al., 2002; Purnell et al., 2004; Escudero-Gilete et al., 2005; Huezo et al., 2005; Hricova et al., 2008; Kondojoyan and Portaguen, 2008; Boysen and Rosenguist, 2009). Especially hot water, steam, electrolyzed water and irradiation effectively reduce bacterial load. Reductions obtained by hot water, steam and electrolyzed water mainly ranged from 0.9 to 2.1, 2.3 to 3.8 and 1.1 to 2.3 orders of magnitude, respectively. However, hot water or steam might affect an adverse impact on carcass appearance. Chemical interventions primarily include organic acids, chlorine-based treatments or phosphate-based treatments (Sakhare et al., 1999; del Rio et al., 2007; Stopforth et al., 2007). Thereby, acetic and lactic acid, acidified sodium chlorite and trisodium phosphate mainly yield reductions in the range from 1.0 to 2.2 orders of magnitude. Besides, some combination treatments further enhance the reductions. However, organic matter often reduces the antimicrobial activity of chemicals. Furthermore, biological interventions (e.g., bacteriophages) constitute promising alternatives, but further investigations are required. Although the mentioned interventions reduce the bacterial loads on poultry carcasses to some extent, decontamination treatments always must be considered as part of an integral food safety system (Loretz et al., 2010).

CONCLUDING REMARKS

As described above, the EU legislation approach on meat safety assurance, advocates use of strict preventive hygiene measures and procedures to overcome the threat posed by pathogens. Therefore, there is no need for carcass decontamination at the last stage of slaughtering process, using intervention methods. On the other hand, USA permitted and regulated intervention decontamination methods. Generally, a HACCP system (i) may use intervention treatments, such as hot water washing or steam pasteurization, (ii) may be based solely on a non-intervention system or (iii) may use a combination of both. Interventions have the advantage of achieving a consistent reduction in bacterial contamination and require less manual input. However, these may lead to carcass decolouration and also produce large quantities of waste water, as well as being relatively expensive to set-up and run. Moreover, there is the argument that intervention methods, such as organic acid application, could be a means of concealing poor hygiene during slaughtering or, even more, their residues could be a potential hazard for food safety. Non-intervention systems, on the other hand, have the advantages of being relatively inexpensive, easy to implement and are more preventive, as far as the exact cause of carcass contamination is identified, allowing preventative corrective actions to take place. However, these systems rely heavily on human effort and the possibility for error is considerably higher than for the intervention systems. Therefore, personnel training and commitment is crucial to ensure their effectiveness.

In our opinion, applying strict preventive hygiene measures and procedures during HACCP implementation in slaughterhouses should be sufficient enough for meat safety assurance. The microbiological data should be interpreted only to assess general trends in the hygiene process of the operator, in order to take corrective action. Therefore, intervention decontamination methods could be a means of concealing poor hygiene. Furthermore, all decontamination methods have disadvantages, as described in the present review, and could be a potential hazard for food safety, mainly by producing residues. In addition, they are relatively expensive to set-up and run.

Nevertheless, we agree with the recent legislation approving use of lactic acid to reduce surface contamination on bovine carcases, as far as carcass sampling for hygiene criteria in accordance to EU Regulations 2073/2005 and 1441/2007 takes place before decontamination. We also believe that steam pasteurization constitutes the most promising alternative. Intervention decontamination methods should be obligatory in specific cases, such as slaughtering under specific conditions determined during the post mortem inspection (e.g., very dirty animals).

CONFLICT OF INTEREST STATEMENT

The authors report no conflict of interest.

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