

## Journal of the Hellenic Veterinary Medical Society

Vol 65, No 2 (2014)



### Carcass decontamination methods in slaughterhouses: a review

K. MILIOS (Κ. ΜΗΛΙΟΣ), E. H. DROSINOS (Ε. ΔΡΟΣΙΝΟΣ), P. E. ZOIPOULOS (Π.Ε. ΖΩΪΟΠΟΥΛΟΣ)

doi: [10.12681/jhvms.15517](https://doi.org/10.12681/jhvms.15517)

#### To cite this article:

MILIOS (Κ. ΜΗΛΙΟΣ) Κ., DROSINOS (Ε. ΔΡΟΣΙΝΟΣ) Ε. Η., & ZOIPOULOS (Π.Ε. ΖΩΪΟΠΟΥΛΟΣ) Π. Ε. (2017). Carcass decontamination methods in slaughterhouses: a review. *Journal of the Hellenic Veterinary Medical Society*, 65(2), 65–78. <https://doi.org/10.12681/jhvms.15517>

## **Carcass decontamination methods in slaughterhouses: a review**

**Milios K.<sup>1</sup>, Drosinos E.H.<sup>2</sup>, Zoiopoulos P.E.<sup>3</sup>**

<sup>1</sup>*Veterinary Service, Regional Administration of Western Greece, Patras, Greece.*

<sup>2</sup>*Laboratory of Food Quality Control and Hygiene, Department of Food Science and Technology, Agricultural University of Athens, Athens, Greece.*

<sup>3</sup>*Laboratory of Animal Science, School of Management of Natural Resources and Enterprises, University of Ioannina, Agrinio, Greece.*

## **Μέθοδοι εξυγίανσης σφάγιων σε σφαγεία: ανασκόπηση**

**Μήλιος Κ.<sup>1</sup>, Δροσινός Ε.<sup>2</sup>, Ζωϊόπουλος Π.<sup>3</sup>**

<sup>1</sup>*Διεύθυνση Κτηνιατρικής Περιφέρειας Δυτικής Ελλάδας, Πάτρα.*

<sup>2</sup>*Εργαστήριο Ποιοτικού Ελέγχου και Υγιεινής Τροφίμων, Τμήμα Επιστήμης και Τεχνολογίας Τροφίμων, Γεωπονικό Πανεπιστήμιο Αθηνών, Αθήνα.*

<sup>3</sup>*Εργαστήριο Ζωικής Παραγωγής, Σχολή Διαχείρισης Φυσικών Πόρων και Επιχειρήσεων, Πανεπιστήμιο Ιωαννίνων, Αγρίνιο.*

**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

*Correspondence:* K. Milios,  
Veterinary Service, Regional Administration of Western Greece,  
21 Zaimi, 26110 Patras, Greece.  
E-mail: milios@aitnia.gr

*Αλληλογραφία:* Κ. Μήλιος,  
Διεύθυνση Κτηνιατρικής Περιφέρειας  
Δυτικής Ελλάδας, Ζαΐμη 21, Πάτρα 26110.  
E-mail: milios@aitnia.gr

*Date of initial submission:* 11 October 2013  
*Date of revised submission:* 10 November 2013  
*Date of acceptance:* 12 November 2013

*Ημερομηνία αρχικής υποβολής:* 11 Οκτωβρίου 2013  
*Ημερομηνία αναθεωρημένης υποβολής:* 10 Νοεμβρίου 2013  
*Ημερομηνία αποδοχής:* 12 Νοεμβρίου 2013

**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 meth-

ods 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 carcasses 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 carcasses 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 carcasses, 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 carcasses, half carcasses 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 °C and not exceeding 30 s, (vi) hot water sprays at >74 °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 re-

ducing 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 °C) or warm (15-40 °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). McEvoy 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 bacteria, 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 °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 °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 through 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<sub>10</sub> cfu cm<sup>-2</sup> and 0.72 log<sub>10</sub> cfu cm<sup>-2</sup>, 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), chlorine, DBDMH (1,3-Dibromo-5,5 dimethylhydantoin), electrolyzed water, H<sub>2</sub>O<sub>2</sub>, 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<sub>2</sub>O<sub>2</sub> and ozone reduced naturally occurring bacteria on carcasses by 1.0-1.1 and 1.1-1.3 log CFU cm<sup>-2</sup>, 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 °C, (ii) hot water wash water (water temperature 95 °C, pressure 1.63 atm for 5 s) or (iii) lactic acid solution (2%) application at 55 °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 °C, 3.4 atm, 5.6 s), rinsing with lactic acid solution (2%, 38-54 °C, 2.04 atm, 5.6 s), rinsing with water (21-54 °C, 2.65 atm, 20 s) and, finally, rinsing with lactic acid solution (2%, 38-54 °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<sup>-2</sup> 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<sup>-2</sup> 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 appli-

cation 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 Faria, 1991; Farkas, 1998; Avens et al., 2002; Fabrizio 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 Rosenquist, 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 carcasses, 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. ■

## REFERENCES

- Algino RJ, Ingham SC, Zhu J (2007) Survey of antimicrobial effects of beef carcass intervention treatments in very small state-inspected slaughter plants. *J Food Sci* 72:173-179.
- Anon. (1996) Pathogen reduction: hazard analysis and critical control point (HACCP) systems. Final rule. United State Department of Agriculture (USDA), Food Safety Inspection Service (FSIS), Washington, DC. Federal Register 61:144, 38806-38989.
- Anon. (2004a) Commission Regulation (EC) No. 852/2004 of 29 April 2004 for Food Hygiene. *Off J Eur Union L226*, 25/6/2004, pp 3-21.
- Anon. (2004b) Regulation (EC) No 853/2004 of the European Parliament and the Council of 29 April 2004 laying down specific hygiene rules on the hygiene of foodstuffs. *Off J Eur Union L226*, 25/6/2004, pp 22-82.
- Anon. (2004c) Regulation (EC) No 854/2004 of the European Parliament and the Council of 29 April 2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. *Off J Eur Union L226*, 25/6/2004, pp 83-127.
- Anon. (2005) Commission Regulation (EC) No. 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. *Off J Eur Union L338*, 22/12/2005, pp 1-26.
- Anon. (2007) Commission Regulation (EC) No. 1441/2007 of 5 December 2007 an amendment of the Commission Regulation (EC) No. 2073/2005 on microbiological criteria for foodstuffs. *Off J Eur Union L322*, 7/12/2007, pp 12-29.
- Anon. (2009) Regulation (EC) No 1069/2009 of the European Parliament and the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation). *Off J Eur Union L300*, 14/11/2009, pp 1-33.
- Anon. (2011) Commission Regulation (EC) No 142/2011 of 25 February 2011 implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive. *Off J Eur Union L54*, 26/2/2011, pp 1-254.
- Anon. (2013) Commission Regulation (EC) No 101/2013 of 4 February 2013 concerning the use of lactic acid to reduce microbiological surface contamination on bovine carcasses. *Off J Eur Union L34*, 4/2/2013, pp 1-3.
- Arthur TM, Wheeler TL, Shackelford SD, Bosilevac JM, Nou X, Koohmaraie M (2005) Effects of low-dose, low-penetration electron beam irradiation of chilled beef carcass surface cuts on *Escherichia coli* O157:H7 and meat quality. *J Food Protect* 68: 666-672.
- Arthur TM, Kalchayanand N, Bosilevac JM, Brichta-Harhay DM, Shackelford SD, Bono JL, Wheeler TL, Koohmaraie M (2008) Comparison of effects of antimicrobial interventions on multidrug-resistant *Salmonella*, susceptible *Salmonella*, and *Escherichia coli* O157:H7. *J Food Protect* 71: 2177-2181.
- Avens JS, Albright SN, Morton AS, Prewitt BE, Kendall PA., Sofos JN (2002) Destruction of microorganisms on chicken carcasses by steam and boiling water immersion. *Food Control* 13: 445-450.
- Bacon RT, Belk KE, Sofos JN, Clayton RP, Reagan JO, Smith GC (2000) Microbial populations on animal hides and beef carcasses at different stages of slaughter in plants employing multiple-sequential interventions for decontamination. *J Food Protect* 63, 1080-1086.
- Bell KY, Cutter CN, Sumner SS (1997) Reduction of foodborne micro-organisms on beef carcass tissue using acetic acid, sodium bicarbonate, and hydrogen peroxide spray washes. *Food Microb* 14: 439-448.
- Bigwood T, Hudson JA, Billington C, Carey-Smith GV, Heinemann JA (2008) Phage inactivation of foodborne pathogens on cooked and raw meat. *Food Microbiol* 25: 400-406.
- Biss ME, Hathaway SC (1996) Microbiological contamination of ovine carcasses associated with the presence of wool and faecal material. *J Bacteriol* 81: 594-600.
- Bolton DJ, Doherty AM, Sheridan JJ (2001) Beef HACCP: intervention and non-intervention systems. *Intern J Food Microb* 66: 119-129.
- Bolton DJ, Oser AH, Cocoma GJ, Palumbo SA, Miller A (1999) Integrating HACCP and TQM reduces pork carcass contamination. *Food Technol* 53: 40 - 43.
- Bosilevac JM, Wheeler TL, Rivera-Betancourt M, Nou X, Arthur TM, Shackelford SD, Kent MP, Jaroni D, Osborn MS, Rossman M, Reagan JO, Koohmaraie M (2004) Protocol for evaluating the efficacy of cetylpyridinium chloride as a beef hide intervention. *J Food Protect* 67: 303-309.
- Boysen L, Rosenquist H (2009) Reduction of thermotolerant *Campylobacter* species on broiler carcasses following physical decontamination at slaughter. *J Food Protect* 72: 497-502.
- Byrne CM, Bolton DJ, Sheridan JJ, McDowell DA, Blair IS (2000) The effects of preslaughter washing on the reduction of *Escherichia coli* O157:H7 transfer from cattle hides to carcasses during slaughter. *Lett Appl Microb* 30: 142-145.
- Byrne B, Dønne G, Lyng J, Bolton DJ (2007) The development of a 'clean sheep policy' in compliance with the new hygiene regulation (EC) 853/2004. *Food Microb* 24: 301-304.
- Cabedo L, Sofos JN, Smith GC (1996) Removal of bacteria from beef tissue by spray washing after different times of exposure to fecal material. *J Food Prot* 59:1284-1287.
- Callaway TR, Anderson RC, Endrington TS, Genovese KJ, Harvey RB, Poole TL, Nisbet DJ (2004) Recent pre-harvest supplementation strategies to reduce carriage and shedding of zoonotic enteric bacterial pathogens in food animals. *Anim Health Res Rev* 5: 35-47.
- Callaway TR, Endrington TS, Loneragan GH, Carr MA, Nisbet DJ (2013) Shiga Toxin-Producing *Escherichia coli* (STEC) Ecology in Cattle and Management Based Options for Reducing Fecal Shedding. *Agric Food Anal Bacteriol* 3: 39-69.
- Carpenter CE, Smith JV, Broadbent JR (2011) Efficacy of washing meat surfaces with 2% levulinic, acetic, or lactic acid for pathogen decontamination and residual growth inhibition meat science. *Meat Sci* 88: 256-260
- Castillo A, Dickson JS, Clayton RP, Lucia LM, Acuff GR (1998) Chemical dehairing of bovine skin to reduce pathogenic bacteria and bacteria of fecal origin. *J Food Protect* 61: 623-625.
- Castillo A, Lucia LM, Kemp GK, Acuff GR (1999) Reduction of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium on beef

- carcass surfaces using acidified sodium chlorite. *J Food Protect* 62: 580-584.
- Cray WC, Moon HW (1995) Experimental infection of calves and adult cattle with *Escherichia coli* O157:H7. *Appl Environ Microbiol* 61:1586-1590.
- Crump JA, Griffin PM, Angulo FJ (2002) Bacterial contamination of animal feed and its relationship to human foodborne illness. *Clin Infect Dis* 35:859-865.
- Cutter CN (1999) Combination spray washes of saponin with water or acetic acid to reduce aerobic and pathogenic bacteria on lean beef surfaces. *J Food Protect* 62: 280-283.
- Cutter CN, Dorsa WJ, Handie A, Rodriguez-Morales S, Zhou X, Breen PJ, Compadre CM (2000) Antimicrobial activity of cetylpyridinium chloride washes against pathogenic bacteria on beef surfaces. *J Food Protect* 63: 593-600.
- Cutter CN, Rivera-Betancourt M (2000) Interventions for the reduction of *Salmonella* Typhimurium DT 104 and Non-O157:H7 enterohemorrhagic *Escherichia coli* on beef surfaces. *J Food Protect* 63: 1326-1332.
- Cutter CN, Siragusa GR (1994) Decontamination of beef carcass tissue with nisin metabolites, reduced bacterial growth by using a pilot scale model carcass washer. *Food Microbiol* 11: 481-489.
- Cutter CN, Siragusa GR (1995) Application of chlorine to reduce populations of *Escherichia coli* on beef. *J Food Safety* 15: 67-75.
- Daniels MJ, Hutchings MR, Greig A (2003) The risk of disease transmission to livestock posed by contamination of farm stored feed by wildlife excreta. *Epidemiol Infect* 130:561-568.
- Davis MA, Cloud-Hansen KA, Carpenter J, Hovde CJ (2005) *Escherichia coli* O157:H7 in environments of culture-positive cattle. *Appl Environ Microbiol* 71:6816-6822.
- del Rio E, Panio-Moran M, Prieto M, Alonso-Calleja C, Capita R (2007) Effect of various chemical decontamination treatments on natural microflora and sensory characteristics of poultry. *Inter J Food Microbiol* 115:268-280.
- Dickson JS, Anderson ME (1992) Microbiological decontamination of food animal carcasses by washing and sanitizing systems: a review. *J Food Protect* 55: 133-140.
- Dickson JS, Nettles Cutter CG, Siragusa GR (1994) Antimicrobial effects of Trisodium phosphate against bacteria attached to beef tissue. *J Food Protect* 57: 952-955.
- Dorsa WJ (1997) New and established carcass decontamination procedures commonly used in the beef-processing industry. *J Food Protect* 60: 1146-1151.
- Dorsa WJ, Cutter CN, Siragusa GR (1996) Evaluation of six beef carcass surface bacterial sampling methods. *Lett Appl Microb* 22: 39-41.
- Dorsa WJ, Cutter CN, Siragusa GR (1997). Effects of acetic acid, lactic acid and trisodium phosphate on the microflora of refrigerated beef carcass surface tissue inoculated with *Escherichia coli* O157:H7, *Listeria innocua*, and *Clostridium sporogenes*. *J Food Protect* 60: 619- 624.
- Ellerbroek LI, Wegener JF, Arndt G (1993) Does spray washing of lamb carcasses alter bacterial surface contamination? *J Food Protect* 56: 432-436.
- Escudero-Gilete ML, Gonzalez-Miret ML, Heredia FJ (2005) Multivariate study of the decontamination process as function of time, pressure and quantity of water used in washing stage after evisceration in poultry meat production. *J Food Eng* 69: 245-251.
- European Food Safety Authority (EFSA) (2010) Scientific Opinion on the safety and efficacy of using recycled hot water as a decontamination technique for meat carcasses. *EFSA Journal* 8(9):1827.
- Fabrizio KA, Sharma RR, Demirci A, Cutter CN (2002) Comparison of electrolyzed oxidizing water with various antimicrobial interventions to reduce *Salmonella* species on poultry. *Poultry Sci* 81: 1598-1605.
- Faith NG, Shere JA, Brosch R, Arnold KW, Ansay SE, Lee MS, Luchansky JB, Kaspar CW (1996) Prevalence and clonal nature of *Escherichia coli* O157:H7 on dairy farms in Wisconsin. *Appl Environ Microbiol* 62:1519-1525.
- Farkas J (1998). Irradiation as a method for decontaminating food. *Intern J Food Microb* 44: 189-204.
- Galland JC, Hyatt DR, Crupper SS, Acheson DW (2001) Prevalence, antibiotic susceptibility, and diversity of *Escherichia coli* O157:H7 isolates from a longitudinal study of beef cattle feedlots. *Appl Environ Microbiol* 67:1619-1627.
- Gill CO (1995) Microbiological contamination of meat during slaughter and butchering of cattle, sheep and pigs. In: (eds.: Pearson AM, Dutson TR) HACCP in meat, poultry and fish processing, Blackie Academic & Professional, London: pp. 118-157.
- Gill CO (2009) Effects on the microbiological condition of product of decontaminating treatments routinely applied to carcasses at beef packing plants. *J Food Protect* 72: 1790-1801.
- Gill CO, Badoni M (2004) Effects of peroxyacetic acid, acidified sodium chlorite or lactic acid solutions on the microflora of chilled beef carcasses. *Intern J Food Microb* 91: 43-50.
- Gill CO, Badoni M, Jones T (1996a) Hygienic effects of trimming and washing operations in a beef-carcass-dressing process. *J Food Protect* 59: 666-669.
- Gill CO, Baker LP (1998) Assessment of the hygienic performance of a sheep carcass dressing process. *J Food Protect* 61: 329-333.
- Gill CO, Bryant J (1997) Decontamination of carcasses by vacuum-hot water cleaning and steam pasteurizing during routine operations at a beef packing plant. *Meat Sci* 47: 267-276.
- Gill CO, Landers C (2003) Microbiological effects of carcass decontaminating treatments at four beef packing plants. *Meat Sci* 65: 1005-1011.
- Gill CO, McGinnis JC (1999) Improvement of the hygienic performance of the hindquarters skinning operations at a beef packing plant. *Intern J Food Microb* 51: 123-132.
- Gill CO, McGinnis JC, Badoni M (1996b) Use of total or *Escherichia coli* counts to assess the hygienic characteristics of a beef carcass dressing process. *Intern J Food Microb* 31: 181-196.
- Gorman BM, Kochevar SL, Sofos JN, Morgan JB, Schmidt GR, Smith GC (1997) Changes on beef adipose tissue following decontamination with chemical solutions or water of 35 °C or 74 °C. *J Musc Foods* 8: 185-197.
- Gorman BM, Sofos JN, Morgan JB, Schmidt GR, Smith GC (1995) Evaluation of handtrimming, various sanitizing agents, and hot water spray-washing as decontamination interventions of beef brisket adipose tissue. *J Food Prot* 58: 899-907.
- Graves Delmore LR, Sofos JN, Schmidt GR, Smith GC (1998) Decontamination of inoculated beef with sequential spraying treatments. *J Food Sci* 63: 890-893.
- Greer GG (2005) Bacteriophages control of foodborne bacteria. *J Food Protect* 68:1102-1111.
- Guan D, Hoover DJ (2005) Emerging decontamination techniques for meat. In: (ed.: Sofos JN) Improving the safety of fresh meat, Woodhead Publishing Ltd, Cambridge: pp. 388-417.
- Hardin MD, Acuff GR, Lucia LM, Oman JS, Savell JW (1995) Com-

- parison of methods for decontamination from beef carcass surfaces. *J Food Protect* 58: 368-374.
- Hricova D, Stephan R, Zweifel C (2008) Electrolyzed water and its application in the food industry. *J Food Protect* 71: 1934-1947.
- Hudson JA, Billington C, Carey-Smith G, Greening (2005) Bacteriophages as biocontrol agents in food. *J Food Protect* 68: 426-437.
- Hudson WR, Mead GC, Hinton M (1998) Assessing abattoir hygiene with a marker organism. *Vet Rec* 142: 542-547.
- Huezo R, Northcutt JK, Smith DP, Fletcher DL, Ingram KD (2007) Effect of dry air or immersion chilling on recovery of bacteria from broiler carcasses. *J Food Protect* 70: 1829-1834.
- Hugas M, Tsigarida E (2008) Pros and cons of carcass decontamination: The role of the European Food Safety Authority. *Meat Sci* 78: 43-52.
- James C, Thornton JA, Ketteringham L, James SJ (2000) Effect of steam condensation, hot water or chlorinated hot water immersion on bacterial numbers and quality of lamb carcasses. *J Food Eng* 43: 219-225.
- Jericho KWF, Kozub GC, Loewen KG, Ho J (1996) Comparison of methods to determine the microbiological contamination of surfaces of beef carcasses by hydrophobic grid membrane filters, standard pour plates or flow cytometry. *Food Microb* 13: 303-309.
- Kalchayanand N, Arthur TM, Bosilevac JM, Brichta-Harhay DM, Guerini MN, Shackelford SD, Wheeler TL, Koohmaraie M (2009) Effectiveness of 1,3-dibromo-5,5 dimethylhydantoin on reduction of *Escherichia coli* O157:H7- and *Salmonella*-inoculated fresh meat. *J Food Protect* 72: 151-156.
- Kang DH, Koohmaraie M, Siragusa GR (2001) Application of multiple antimicrobial interventions for microbial decontamination of commercial beef trim. *J Food Protect* 64: 168-171.
- Kenney PB, Prasai RK, Campbell RE, Kastner CL, Fung DYC (1995) Microbiological quality of beef carcasses and vacuum-packaged subprimals: process intervention during slaughter and fabrication. *J Food Protect* 58: 633-638.
- King DA, Lucia LM, Castillo A, Acuff GR, Harris KB, Savell JW (2005) Evaluation of peroxyacetic acid as a post-chilling intervention for control of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium on beef carcass surfaces. *Meat Sci* 69: 401-407.
- Kochevar SL, Sofos JN, Bolin RR, Reagan JO, Smith GC (1997) Steam vacuuming as a previsceration intervention to decontaminate beef carcasses. *J Food Protect* 60: 107-113.
- Kondjoyan A, Portanguen S (2008) Effect of superheated steam on the inactivation of *Listeria innocua* surface-inoculated onto chicken skin. *J Food Eng* 87: 162-171.
- LeJeune JT, Besser TE, Rice DH, Berg JL, Stilborn RP, Hancock DD (2004) Longitudinal study of fecal shedding of *Escherichia coli* O157:H7 in feedlot cattle: Predominance and persistence of specific clonal types despite massive cattle population turnover. *Appl Environ Microbiol* 70:377-384.
- Loretz M (2011). Antibacterial activity of decontamination treatments for cattle hides and beef carcasses. *Food Control* 22: 347-359.
- Loretz M, Stephan R, Zweifel C (2010) Antimicrobial activity of decontamination treatments for poultry carcasses: A literature survey. *Food Control* 21: 791-804
- Mataragas M, Drosinos EH, Tsola E, Zoiopoulos PE (2012) Integrating statistical process control to monitor and improve carcasses quality in a poultry slaughterhouse implementing a HACCP system. *Food Control* 28: 205-211.
- McEvoy JM, Doherty AM, Sheridan JJ, Bailey DG, Blair IS, McDowell DA (2003) The effects of treating bovine hide with steam at sub-atmospheric pressure on bacterial numbers and leather quality. *Lett Appl Microb* 37: 344-348.
- McEvoy JM, Doherty AM, Sheridan JJ, McGuire JJ, Teagasc L (1999) The incidence of *Listeria* spp. and *Escherichia coli* O157:H7 on beef carcasses. *Hygiene Review* 1999. Society of Food Hygiene and Technology: 1-3.
- Milios K, Mataragas M, Pantouvakis A, Drosinos EH, Zoiopoulos P (2011) Evaluation of control over the microbiological contamination of carcasses in a lamb carcass dressing process operated with or without pasteurizing treatment. *Intern J Food Microb* 146: 170-175.
- Milios K, Mataragas M, Pantouvakis A, Drosinos EH, Zoiopoulos P (2013) Techno-managerial factors related to food safety management system in food business. *Brit Food J* 115(9): 1381 - 1399.
- Mora AJ, Blanco E, Blanco M, Alonso MP, Dhahi G, Echeita A, Gonzalez EA, Bernardez MI, Blanco J (2005) Antimicrobial resistance of Shiga toxin (verotoxin)-producing *Escherichia coli* O157:H7 and non-O157 strains isolated from humans, cattle, sheep and food in Spain. *Res Microbiol* 156:793-806.
- Norrung B, Buncic S (2008) Microbial safety of meat in the European Union. *Meat Sci* 78: 14-24.
- Nutsch DE, Schafer RC, Wilson MJ, Riemann JD, Leising CL, Kastner JR, Wolf AL, Prasai RK (1997) Comparison of steam pasteurization and other methods for reduction of pathogens on surfaces of freshly slaughtered beef. *J Food Protect* 60: 476-484.
- Oliver SP, Patel DA, Callaway TR, Torrence ME (2009) ASAS Centennial Paper: Developments and future outlook for preharvest food safety. *J Anim Sci* 87: 419-437.
- Pearce R, Bolton DJ (2008) The anti-microbial effect of a dairy extract (LactiSAL®) on *Salmonella enterica* Typhimurium and *Escherichia coli* O157:H7 on different beef carcass surfaces. *Food Control* 19: 449-453.
- Penney N, Bigwood T, Barea H, Pulford D, LeRoux G, Cook R, Jarvis G, Brightwell G (2007) Efficacy of a peroxyacetic acid formulation as an antimicrobial intervention to reduce levels of inoculated *Escherichia coli* O157:H7 on external carcass surfaces of hot-boned beef and veal. *J Food Protect* 70: 200-203.
- Prasai RK, Acuff GR, Lucia LM, Hale DS, Savell JW, Morgan JB (1991) Microbiological effects of acid decontamination of beef carcasses at various locations in processing. *J Food Protect* 54: 868-872.
- Purnell G, Mattik K, Humphrey T (2004) The use of 'hot wash' treatments to reduce the number of pathogenic and spoilage bacteria on raw retail poultry. *J Food Eng*, 62: 29-36.
- Ransom JR, Belk KE, Stopforth JD, Sofos JN, Scanga JA, Smith GC (2001) Comparison of new intervention additives/chemicals with interventions presently in use for reducing incidence of *Escherichia coli* O157:H7 on beef cuts and beef trimmings. Final Report submitted to the National Cattlemen.s Beef Association, Englewood, CO, Colorado State University, Fort Collins, pp. 1-22.
- Reagan JO, Acuff GR, Buege DR, Buyck MJ, Dickson JS, Kastner CL, Marsden JL, Morgan JB, Nickelson R, Smith GC, Sofos JN (1996) Trimming and washing of beef carcasses as a method of improving the microbiological quality of meat. *J Food Protect* 59: 751-756.
- Reid C-A, Small A, Avery SM, Buncic S (2002) Presence of food-borne pathogens on cattle hides. *Food Control* 13: 411-415.
- Sakhare PZ, Sachindra NM, Yashoda KP, Narashima Rao D (1999) Efficacy of intermittent decontamination treatments during

- processing in reducing the microbial load on broiler chicken carcass. *Food Control* 10: 189–194.
- Sams AR, Feria R (1991) Microbial effects of ultrasonication of broiler drumstick skin. *J Food Sci* 56: 247–248.
- Sargeant JM, Sanderson MW, Griffin DD, Smith RA (2004) Factors associated with the presence of *Escherichia coli* O157 in feedlot-cattle water and feed in the Midwestern USA. *Prev Vet Med* 66:207–237.
- Schnell TD, Sofos JN, Littlefield VG, Morgan JB, Gorman BM, Clayton RP, Smith GC (1995) Effects of postexsanguination dehairing on the microbial load and visual cleanliness of beef carcasses. *J Food Protect* 58: 1297–1302.
- Schrezenmeir J, de Vrese M (2001) Probiotics, prebiotics, and synbiotics—Approaching a definition. *Am J Clin Nutr* 73:361–364.
- Sheng HH, Knecht J, Kudva IT, Hovde CJ (2006) Application of bacteriophages to control intestinal *Escherichia coli* O157:H7 levels in ruminants. *Appl Environ Microbiol* 72:5359–5366.
- Sheridan JJ (1998) Sources of contamination during slaughter and measures for control. In: (eds.: Sheridan JJ, O’KeeVe M, Rogers M) *Food safety implications of change from producerism to consumerism*, Food and Nutrition Press, Inc, USA, pp. 137–155.
- Siragusa GR (1995) The effectiveness of carcass decontamination systems for controlling the presence of pathogens on the surfaces of meat animal carcasses. *J Food Safety* 15: 229–238
- Smith DM, Blackford S, Younts R, Moxley J, Gray L, Hungerford T, Milton, Klopfenstein T (2001) Ecological relationships between the prevalence of cattle shedding *Escherichia coli* O157:H7 and characteristics of the cattle or conditions of the feedlot pen. *J Food Prot* 64:1899–1903.
- Stopforth JD, O’Connor R, Lopes M, Kottapalli B, Hill WE, Samadpour M (2007) Validation of individual and multiple sequential interventions for reduction of microbial populations during processing of poultry carcasses and parts. *J Food Protect* 70: 1393–1401.
- Trianti I, Drosinos E, Zoiopoulos P (2008) Establishing HACCP system in small scale enterprise for traditional meat products. *Italian J Food Sci* 20: 427–432.
- Tsola E, Drosinos E, Zoiopoulos P (2008) Impact of poultry slaughterhouse modernization and updating of food safety management systems on the microbiological quality and safety of products. *Food Control* 19: 423–431.
- Woerner D, Ransom J, Sofos JN, Scanga JA, Smith GC, Belk KE (2006) Preharvest processes for microbial control in cattle. *Food Prot Trends* 26:393–400.
- Wetzel AN, LeJeune JT (2006) Clonal dissemination of *Escherichia coli* O157:H7 subtypes among dairy farms in northeast Ohio. *Appl Environ Microbiol* 72:2621–2626.
- Yalcin S, Nizamlioglu M, Gurbuz U (2004) Microbiological conditions of sheep carcasses during the slaughtering process. *J Food Safety* 24: 87–93.