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Microbial Performance of Food Safety Management Systems Implemented in the Lamb Production Chain

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ABSTRACT

The actual microbial status of the lamb production chain at three slaughterhouses, one processing plant, and five butcher shops selling whole or cut lamb carcasses to consumers was assessed with a previously developed microbial assessment scheme. All studied establishments had a food safety management system (FSMS) that was implemented according to legislative requirements. Microbial safety level profiles were constructed for each establishment and provided clear indications of which pathogens, hygiene indicators, or utility parameters required attention to improve the performance of the microbiological control protocols of the implemented FSMS. The highest contamination was found in the slaughterhouses in samples taken from the meat products (aerobic mesophilic plate counts [AMPs] of 3.40 to 6.63 log CFU/cm^2 and *Enterobacteriaceae* counts of 1.00 to 4.62 log CFU/cm^2), contact surfaces (AMPs of 2.44 to 8.92 log CFU/cm^2), and operators' hands and/or gloves (AMPs of 2.84 to 8.09 log CFU/cm^2), especially after hide removal and evisceration. The microbial assessment scheme is a useful tool for providing insight into the actual microbiological results achieved with an FSMS implemented in establishments at various stages along the lamb production chain.

Fresh suckling lamb meat is a typical and traditional product in Spain, especially in the Castilla y León region. The European Union (EU) granted this meat a protected geographical indication in 1999 (Commission Regulation EEC No 2107/1999) with the name ''Lechazo de Castilla y León.'' The sensory characteristics of this product most appreciated by consumers are its light color (pearly white to pink), tenderness, juiciness, smooth texture, and distinctive flavor *(20)*. In addition to sensory qualities, safety is a basic requirement for this product. Numerous foodborne pathogens have been implicated as a cause of human illness along the lamb production chain; Shiga toxin–producing *Escherichia coli, Listeria monocytogenes, Salmonella,* and *Staphylococcus aureus* are the most prominent of these pathogens *(10, 15, 33, 38, 48)*. In Europe in 2007, lamb meat was implicated in one outbreak of salmonellosis and two episodes of *S. aureus* intoxication *(16, 44)*.

Several researchers have independently evaluated the microbial contamination of ruminant meats and environmental surfaces at the different stages of the lamb production chain, i.e., in slaughterhouses, processing plants, and butcher shops *(8, 9, 51, 53, 57)*. Lenahan et al. *(37)* in Ireland and Sumner et al. *(55)* in Australia found various *E. coli* serovars, including *E. coli* O157:H7, in lamb carcasses in slaughterhouses. *Salmonella* has been found in lamb carcasses in slaughterhouses *(52, 53)* and in processing plant facilities as has Shiga toxin–producing *E. coli (33)*. Various *E. coli* serovars have been found in lamb meat and on workers' hands, equipment, and food surfaces in butcher shops *(15, 51)*. Rajpura et al. *(47)* reported an *E. coli* infection outbreak due to cross-contamination of a butcher's counter. However, to the best of our knowledge, no concurrent microbiological assessment has been performed along the lamb production chain despite the fact that several authors have stressed the need to control the presence of pathogens from farm to fork *(44, 54)*. Jacxsens et al. *(32)* developed a microbial assessment scheme (MAS) to identify critical sampling locations, select microbiological parameters, assess the sampling and analytical methods, and process and interpret the resulting data. This approach has been successfully used by Sampers et al. *(49)* in poultry processing plants. The data obtained using an MAS provide an indication of the actual microbial status achieved upon implementation of a food safety management system (FSMS). Microbiological safety level profiles, indicating which microorganisms are present and to what extent they contribute to food safety, can be derived for a specific food processing company based on an MAS assessment. The basic assumption behind this tool is that low numbers of microorganisms and low variability in microbiological counts indicate an effective FSMS *(32, 40)*.

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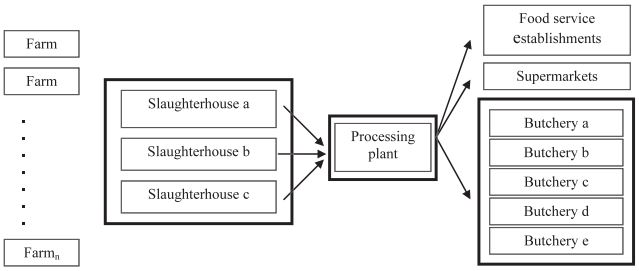

FIGURE 1. *Typical structure of a lamb production chain.*

The objective of this study was to gain insight into the actual microbiological results of implementing an FSMS in establishments along a lamb production chain, to determine the microbial dynamics in that chain, and to discuss different control measures to improve the microbiological food safety output in the lamb production chain.

MATERIALS AND METHODS

Lamb meat. This study focused on Castilla y León suckling lamb, which according to the protected geographical indication regulations can be obtained only from the local sheep breeds Churra, Castellana, and Ojalada and their cross-breeds. Before harvest, live animals must weigh between 9 and 12 kg and must have been fed with maternal milk only.

Selection of establishments along the lamb production chain. Figure 1 shows a typical lamb production chain, in which several suppliers (slaughterhouses) supply one or a few processing sites (chain convergence), which themselves supply various purchasers and/or customers (chain divergence); such structures are typical for food supply chains *(36).* To illustrate this chain with actual figures, the province of Burgos contains 28 registered slaughterhouses, five processing plants, and 333 butcher shops. In this study, three slaughterhouses (SHa, SHb, SHc), one processing plant (PR), and five butcher shops (BHa, BHb, BHc, BHd, BHe), all located in Burgos (Castilla y León, Spain), were selected according to the previous described situations of the various lamb food chain operators in the region. Each slaughterhouse receives live animals from a set of farms throughout the year and transports the lamb carcasses to the same processing plant. This plant then sells the meat to food service establishments, supermarkets, or butcher shops. The slaughterhouses and the processing plant had implemented a FSMS based on good manufacturing practices and hazard analysis critical control point principles, according to European legislation (i.e., EU Regulations 852/2004 and 853/2004). SHc was certified for ISO 9001:2008. However, at the time of the study butchers had implemented only the legal good manufacturing practices.

Identification of critical sampling locations. Following the MAS protocol *(32),* 10 critical sampling locations (CSLs) were defined for the slaughterhouses, 9 for the processing plant, and 7 for butcher shops. The principle behind the MAS is that only those CSLs that provide information on the core control activities in an FSMS are selected. CSLs were defined in the slaughterhouses (S), the processing plant (P), and in butcher shops (B) for food products as S1 (carcass after hide removal), S2 (carcass after evisceration), S3 (carcass after covering with the omentum), S4 (carcass after chilling), P1 (carcass at arrival at processing plant), P2 (meat cut after portioning), P3 (final product after packaging and chilling), B1 (carcass at arrival at butcher shops), and B2 (meat cuts in the display counter). CSLs for food contact surfaces were defined as S5, S6, and S7 (knives at hide removal, evisceration, and place covered with the omentum, respectively, in the slaughterhouses), P4, P5, and P6 (two cutting tables and one working table at packaging in the processing plant), B3, B4, B5, and B6 (cutting table, knife, grading machine, and operators' aprons, respectively, in butcher shops]). CSLs for hands and/or gloves of the personnel were S8, S9, and S10 (at hide removal, evisceration, and place covered with the omentum in the slaughterhouses), P7, P8, and P9 (at reception, cutting, and packaging in the processing plant), and B7 (in the butcher shop).

Selection of microbiological parameters. Food safety parameters were selected according to the MAS protocol. *Salmonella* and *L. monocytogenes* were selected as pathogenic indicators because these bacteria are commonly found in meat products *(4). E. coli* and *Enterobacteriaceae* were selected as hygiene indicators *(4). S. aureus* was selected as an indicator of personal hygiene *(1),* and aerobic mesophilic plate counts (AMPs) were chosen as an indicator of overall microbial quality *(43).* AMPs, *Enterobacteriaceae, E. coli, Salmonella,* and *L. monocytogenes* were analyzed in food products and on contact surfaces, and AMPs, *Enterobacteriaceae, E. coli,* and *S. aureus* were analyzed for hand and glove samples.

Sampling. Samples were taken during three visits to each establishment on 3 days. All CSLs were analyzed at each visit. One sample was taken per day for the food products (CSLs S1 through S4, P1 through P3, and B1 and B2). The food contact surfaces (CSLs S5 through S7, P4 through P6, and B3 through B6) and food handlers' gloves and/or hands (CSLs S8 through S10, P7 through P9, and B7) were sampled three times during one shift (beginning, middle, and end of the production day) to monitor the distribution of contamination during processing. A total of 516 samples (198 samples in the slaughterhouses, 63 samples in the processing plant, and 255 samples in the butcher shops) were collected from the various parts of the lamb production chain.

Samples of carcasses and fresh meat cuts (CSLs S1 through S4, P1 through P3, and B1) were collected using a nondestructive sampling method according to ISO 17604:2003 *(26)* with sterile abrasive sponges (Envirosponge, Biotrace International, Bridgend, UK). Four sites were sampled on carcasses (flank, lateral thorax, brisket, and breast), with a sampling area of 50 cm^2 per sampling site. Fresh meat cuts were sampled using a single abrasive sponge (Envirosponge) over an area of 100 cm^2. Sampling areas were delimited with a sterile template (Biotrace). Sterile premoistened abrasive sponges were used to swab vertically, horizontally, and diagonally over the delimited area. After swabbing, the sponges were placed individually in sterile plastic bags containing 100 ml of buffered peptone water (AES Chemunex, Bruz, France) for subsequent determination of total mesophile, *Enterobacteriaceae, E. coli,* and *L. monocytogenes* counts and the detection of *Salmonella* and in 100 ml of demi-Fraser solution (Oxoid, Basingstoke, UK) for the detection of *L. monocytogenes*. The samples were stored and transported to the laboratory for further microbial analysis in a cool box maintained at 4°C and analyzed within 6 h of sampling.

Samples of final products (CSL B2) were collected using a destructive method according to the sampling preparation method described in ISO 6887-2:2003 *(27).* Samples of meat (300 g) were removed at the establishment with a sterile knife. These samples were stored aseptically in sterile plastic bags, transported to the laboratory for further microbial analysis in a cool box maintained at 4°C, and analyzed within 6 h of sampling.

Environmental samples (CSLs S5 through S10, P4 through P9, and B3 through B7) were collected using a nondestructive method according to ISO 18593:2004 *(30)*. A sterile template (Biotrace) was used to delineate a sampling area of 25 cm^2. Sterile premoistened cotton swabs (Eurotube, Deltalab, Rubí, Barcelona, Spain) in 10 ml of buffered peptone water (AES) were used to swab the working tables for subsequent determination of total mesophile, *Enterobacteriaceae, E. coli, L. monocytogenes,* and *S. aureus* counts and detection of *Salmonella* and in 10 ml of demi-Fraser solution (Oxoid) for the detection of *L. monocytogenes*. A new sterile swab was used for each food contact surface and analytical parameter. After sampling, the swabs were inserted aseptically back into their respective tubes containing 10 ml of the respective medium. The tubes were then tightly closed, stored, and transported to the laboratory for further microbial analysis in a cool box maintained at 4°C; all samples were analyzed within 6 h of sampling.

Sample preparation. Various sample preparation techniques were applied to abrasive sponges, cotton swabs, and meat samples in the laboratory before microbiological analysis. Abrasive sponges were homogenized for 2 min, whereas tubes containing cotton swabs were vortex mixed for 10 s. Twenty-five of the 300 g of fresh meat collected (CSL B2) was homogenized with 225 ml of buffered peptone water for 2 min in a sterile plastic bag in a lab blender (Stomacher 400, Seward, London, UK) for subsequent determination of AMPs and *Enterobacteriaceae, E. coli, Salmonella,* and *L. monocytogenes* counts. Ten grams was removed from the original 300-g sample and mixed with 90 ml of demi-Fraser solution for the detection of *L. monocytogenes*.

Analytical methods. Before detection and counting, samples were serially diluted (1:10), and the resulting bacterial suspensions were plated and incubated according to the appropriate ISO method. For AMPs, plate count agar (Oxoid) was incubated for 72 h at 30°C (ISO 4833:2003) *(28)*. For enumeration of *Enterobacteriaceae,* violet red bile glucose agar (Oxoid) was incubated 24 to 48 h at 37°C (ISO 21528-2:2004) *(31)*. For enumeration of *E. coli,* tryptone bile X-glucuronide agar (Biolife, Milano, Italy) was incubated for 24 h at 42°C (ISO 16649-2:2001) *(24)*. Baird Parker agar (Biolife) was used for *Staphylococcus* enumeration, and confirmation of *S. aureus* was performed with rabbit plasma (AES) (ISO 6888-1:1999 Amd 1:2003) *(29)*. For detection of *L. monocytogenes,* demi-Fraser and Fraser were used as preenrichment and enrichment media (Oxoid), respectively, and cultures were directly plated onto chromogenic *Listeria* agar base (Oxoid) and incubated at 37°C for 48 h. When *L. monocytogenes* was detected, enumeration was performed with buffered peptone water and chromogenic *Listeria* agar base (ISO 11290-1:1996 and ISO 11290-2:1998) *(22, 23)*. *Salmonella* was detected using Rappaport-Vassiliadis broth (with soy) and Muller-Kauffmann tetrathionate broth base (with novobiocin) (Biolife) as selective enrichment media and directly plated onto xylose lysine deoxycholate agar (Biolife) and *Salmonella* agar (AES) plates incubated at 37°C for 24 h (ISO 6579:2002) *(25)*.

Data processing and interpretation. Regulatory criteria (EU Regulation 2073/2005) and microbiological guidelines *(56)* (Table 1) were used to interpret the data collected. When a nondestructive sampling method is used, only a fraction of the cells are captured *(3, 12, 42)*. Therefore, the recommendation of the Belgian Food Safety Agency Scientific Committee was adapted for interpretation of the data, i.e., the fraction of captured cells was considered 0.5 log units lower for the nondestructive method than for the destructive method for both *Enterobacteriaceae* and total counts. Consequently, the criteria for evaluating process hygiene evaluation were adjusted by this value *(32)*.

Because no official recommendations exist for assessing the microbial load limits on working surfaces, we consulted experts in this field and decided on the following criteria: surfaces or operators' hands and/or gloves on which microbial contamination was equal to or higher than that of the meat at the same CSL were considered unacceptable. In contrast, surfaces with lower microbial contamination levels than the meat samples collected at the same CSL were considered acceptable.

Microbial safety level profile. Once the MAS data had been compiled and interpreted based on the criteria described above, a microbial safety profile was constructed. The microbial safety level can be classified on a scale of 1 to 3, where level 3 reflects good food safety (legal criteria or guidelines are met; no improvements to the FSMS are needed), level 2 reflects moderate food safety (legal criteria or guidelines are violated; improvements are needed to a single protocol of the FSMS), and level 1 reflects poor food safety (legal criteria or guidelines are violated; improvements are needed to several protocols of the FSMS). The sum of the levels of the individual microbiological parameters analyzed is reflected in a microbial food safety level profile, as established by Jacxsens et al. *(32)*. A score was assigned to express the overall food safety performance of the current FSMS for each establishment (six microbiological parameters produce a maximum score of 18). An overall score of 1 was assigned when the sum of the levels was 6 or 7, a sum of 8 to 10 resulted in an overall score of 1-2, a sum of 11 to 13 resulted in an overall score of 2, a sum of 14 to 16 resulted in an overall score of 2-3, and a sum of 17 or 18 resulted in an overall score of 3.

RESULTS AND DISCUSSION

Microbial safety level profiles were constructed for the different establishments in the lamb production chain to obtain a first indication about the actual microbiological results achieved by implementation of their FSMSs (Fig. 2). None of the establishments achieved a maximum score of 18, indicating room for improvement in the microbiological protocols of their respective FSMSs. However, the overall assigned score tended to increase from slaughterhouse to processing plant to butcher shop (from 2 to 2-3). The food safety level profiles allowed different microbiological problems to be identified along the chain.

In general, the current FSMSs seemed to perform sufficiently for control of the selected pathogens *Salmonella* and *L. monocytogenes*. The exception was slaughterhouse SHc, where a level 1 was obtained for *Salmonella*. This pathogen was found on carcasses after hide removal and in samples taken from knives, which indicates that more protocols in the FSMS are insufficient *(39)*. The main source of *Salmonella* probably is the incoming live lambs *(19, 52)*. Various authors have reported that pathogens such as *Salmonella* and *E. coli* O157:H7 can be transferred from the hide to the carcass *(5, 6, 11, 45),* which can easily lead to contamination of subsequent process steps when no interventions are applied to reduce the pathogens to acceptable levels *(40)*. Efficient cleaning and disinfection procedures are needed to prevent cross-contamination and spread of pathogens in production areas.

TABLE 1. *Regulatory criteria and microbiological guidelines for interpretation of results*[a]

Reference	Food products[b]		Contact surfaces: CSLs S5, S6, S7, P4, P5, P6, B3, B4, B5, B6	Hands and/or gloves: CSLs S8, S9, S10, P7, P8, P9, B7
	Carcasses: CSLs S1, S2, S3, S4, P1, B1	Fresh meat cuts and final products: CSLs P2, P3, B2		
EU Regulation 2073/2005 category 2.1.1	AMP m = 3.5 log CFU/cm^2 M = 5.0 log CFU/cm^2 *Enterobacteriaceae* m = 1.5 log CFU/cm^2 M = 2.5 log CFU/cm^2 *Salmonella* absent in the area tested			
Uyttendaele et al. *(56)*	*E. coli* absent in the area tested *L. monocytogenes*: absent in the area tested	AMP m = 5.5 log CFU/cm^2 M = 6.5 log CFU/cm^2 *Enterobacteriaceae* m = 2.5 log CFU/cm^2 M = 3.5 log CFU/cm^2 *E. coli* m = 1.5 log CFU/cm^2 M = 2.5 log CFU/cm^2 *Salmonella* absent in the area tested *L. monocytogenes* absent in the area tested	*Salmonella* and *L. monocytogenes* absent in the area tested	*S. aureus* below detection limit (<100 CFU/cm^2)
This study			*E. coli, Enterobacteriaceae,* and AMP: surfaces whose microbial contamination is equal to or higher than that present in the meat at the same CSL are considered unacceptable	*E. coli, Enterobacteriaceae,* and AMP: surfaces whose microbial contamination is equal to or higher than that present in the meat at the same CSL are considered unacceptable

[a] CSLs, critical sampling locations, which were designated in three slaughterhouses (S1 through S10), one processing plant (P1 through P9), and five butcher shops (B1 through B7). S1, carcass after hide removal; S2, carcass after evisceration; S3, carcass after covering with the omentum; S4, carcass after chilling; S5, S6, and S7, knives at hide removal, evisceration, and place covered with the omentum, respectively; S8, S9, and S10, hands or gloves at hide removal, evisceration, and place covered with the omentum, respectively; P1, carcass at arrival; P2, meat cut after portioning; P3, final product after packaging and chilling; P4, P5, and P6, two cutting tables and one working table, respectively, at packaging; P7, P8, and P9, hands or gloves at reception, cutting, and packaging, respectively; B1, carcass at arrival; B2, meat cuts in the display counter; B3, cutting table; B4, knife; B5, grading machine; B6, operators' apron; B7, hands and/or gloves of the personnel.

[b] Microbial limits in food products: *m,* lower limit; *M,* upper limit.

For the hygiene indicators (*Enterobacteriaceae* and *E. coli*) and the utility parameter (AMP), more marked differences were found resulting in lower microbial safety scores for the slaughterhouses than for the butcher shops (Fig. 2). Level 1 was assigned to *Enterobacteriaceae, E. coli,* and AMP in the slaughterhouses and processing plant, and level 2 was assigned to these parameters for the butcher shops. Further explanation is given in Figure 3.

Figure 3A shows the distribution profiles of AMPs based on the data from the product samples taken from the carcasses and meat cuts at the subsequent steps in the various establishments. For the slaughterhouses, Figure 3A indicates a decrease in AMP in the steps from hide removal to chilling. This result is in agreement with those of other researchers, who found that hide removal was a major source of contamination *(42, 48).* The hide may contain bacterial counts as high as 10^7 to 10^8 CFU/g *(34).* After chilling, the AMP remained constant or decreased slightly at evisceration and covering with the omentum in the slaughterhouses. According to McEvoy et al. *(42),* the reductions after chilling are unlikely to be due to cell death and are more likely the result of cell injury from reduced water activity and temperature at the carcass surface. Figure 3A also shows that AMP tended to decrease in the two CSLs at the processing plant but then appeared to increase, as reflected by the higher counts at the packaging stage. This increase could be due to the high level of manipulation (various handlers and equipment), which can lead to cross-contamination *(18, 40, 42).* Temperature abuse at the processing plant also could contribute to an increase in AMP *(21).* The AMPs at the butcher shops appeared to increase even further in the steps before sale of the product, possibly because of temperature abuse in the butcher shops *(21).* In these shops, the meat is cut with knives into smaller

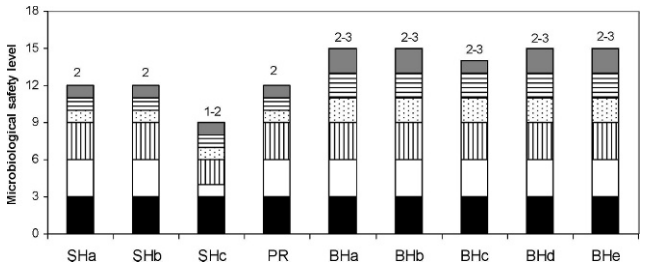

FIGURE 2. *Microbial safety level profiles (bar) and food safety scores (individual parameters) for all the establishments (slaughterhouses SHa, SHb, and SHc; processing plant PR; butcher shops BHa, BHb, BHc, BHd, and BHe). The profile was constructed by assigning a score of 1 to 3 for each analyzed parameter. Shaded, aerobic mesophilic plate counts; horizontal lines,* Enterobacteriaceae*; dots,* E. coli*; vertical lines,* S. aureus*; open,* Salmonella*; solid,* L. monocytogenes. *Assigned scores were calculated following the protocol of Jacxsens et al. (32).*

pieces, thereby increasing the total surface area available for colonization and increasing the water activity at the meat surface, which favors microbial growth *(2)*. Cross-contamination during manipulation also can occur *(18, 40, 42)*.

In addition to the trend of increasing AMPs along the chain, the variability in AMPs was high at all CSLs (Fig. 3A). At the slaughterhouses, AMPs of 3.40 to 6.63 log CFU/cm^2 were found on the carcass after hide removal, although variability was lower after chilling. High variability also was noted for carcasses arriving at the processing plant (2.61 to 4.32 log CFU/cm^2), whereas the AMPs for the processed carcasses upon arrival in the butcher shops were 3.48 and 6.40 log CFU/cm^2. This variability in AMP indicates that the current FSMSs are not (yet) able to control contamination and ensure meat products with predictable microbiological tolerances *(32, 39)*.

Figure 3B and 3C shows the *Enterobacteriaceae* and *E. coli* counts in the carcass and cut meat samples taken at the CSLs along the lamb production chain. A comparison of the *Enterobacteriaceae* and *E. coli* data across CSLs reveals that increases are closely related to the packaging step at the processing plant, suggesting that fecal contamination (in the slaughterhouses) probably is the major cause for these high counts *(4, 43)*. However, *Enterobacteriaceae* other than *E. coli* were introduced into the lamb production chain after packaging. Therefore, the high *Enterobacteriaceae* counts found in the samples taken at the butcher shops probably came from other sources, such as environmental surfaces, added ingredients (spices), or the growth of enterobacteria other than *E. coli (43)*. As for the AMPs, the variability in *Enterobacteriaceae* and *E. coli* counts was very high in the slaughterhouses (1.00 to 4.62 log CFU/cm^2 for *Enterobacteriaceae* and 1.10 to 3.81 log CFU/cm^2 for *E. coli* in the omentum step), although for the samples taken after the chilling step the variability decreased slightly (1.24 to 2.00 log CFU/cm^2 for *Enterobacteriaceae* except one sample that had a count of 4.84 CFU/cm^2).

The results obtained from environmental swabs (Table 2) indicate that for AMPs, *Enterobacteriaceae* counts, and *E. coli* counts 88% (143 of 162), 76% (123 of 162), and 80% (130 of 162) of the samples, respectively, taken in the

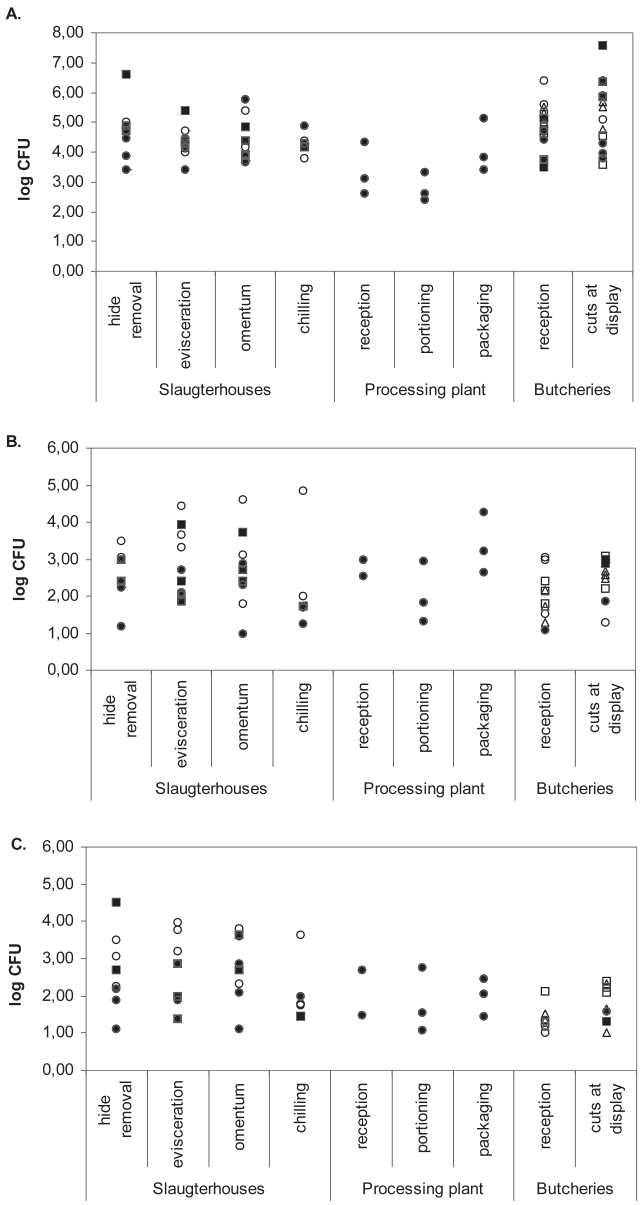

FIGURE 3. *Distribution of aerobic mesophilic plate counts (A),* Enterobacteriaceae *(B), and* E. coli *(C) for meat critical sampling locations (CSLs) (*n *= 3 × 3 for each CSL in slaughterhouses;* n *= 3 for each CSL in the processing plant;* n *= 5 × 3 for each CSL in butcher shops). Units are log CFU per square centimeter for all CSLs except for the samples taken from the displays in the butcher shops (log CFU per gram). Detection limit was 1 log CFU.* ●*, SHa, PR, BHa;* ○*, SHb, BHb;* ■*, SHc, BHc;* □*, BHd;* △*, BHe.*

slaughterhouses exceeded the limits. For the AMPs, *Enterobacteriaceae* counts, and *E. coli* counts obtained from the processing plant, 46% (25 of 54), 19% (10 of 54), and 17% (9 of 54) of the samples, respectively, exceeded the limits, whereas for these values obtained from the butcher shops, 5% (11 of 225), 8% (18 of 225), and 0% (0 of 225), respectively, of the samples exceeded the limits. In all samples, AMPs were highly variable, ranging from 4.40 to 8.92 log CFU/cm^2 in slaughterhouses, from below the detection limit to 3.84 log CFU/cm^2 in the processing plant, and from below the detection limit to 5.50 log CFU/cm^2 in the butcher shops. The high and variable counts obtained

TABLE 2. *Detailed results of microbial assessment scheme for environment samples*[a]

Sampling site	Sampled area	CSL[b]	Food safety indicators		Hygiene indicators			Overall indicator (AMP[c])
			L. monocytogenes	*Salmonella*	*E. coli*	*Enterobacteriaceae*	*S. aureus*	
SHa	Knives	S5	A	A	ND–4.72 (8/9)	1.54–4.94 (7/9)	NA	4.24–8.15 (6/9)
		S6	A	A	ND–4.39 (6/9)	2.58–5.15 (9/9)	NA	5.71–8.92 (9/9)
		S7	A	A	ND–4.30 (8/9)	2.39–4.32 (8/9)	NA	6.09–8.86 (9/9)
	Hands	S8	NA	NA	ND–5.16 (4/9)	ND–3.48 (5/9)	A	5.32–6.32 (9/9)
		S9	NA	NA	ND–3.79 (8/9)	2.32–4.84 (9/9)	A	5.44–7.19 (9/9)
		S10	NA	NA	1.00–4.43 (9/9)	1.68–3.63 (5/9)	A	4.47–6.79 (9/9)
SHb	Knives	S5	A	A	ND–3.68 (7/9)	ND–4.44 (4/9)	NA	4.02–6.14 (9/9)
		S6	A	A	1.70–5.11 (4/9)	1.54–5.10 (4/9)	NA	2.44–5.54 (4/9)
		S7	A	A	ND–2.84 (3/9)	ND–3.39 (5/9)	NA	3.00–4.45 (4/9)
	Hands	S8	NA	NA	1.74–4.34 (7/9)	1.14–4.76 (5/9)	A	2.84–6.46 (8/9)
		S9	NA	NA	2.14–4.92 (5/9)	2.32–5.36 (4/9)	A	3.44–8.09 (6/9)
		S10	NA	NA	ND–3.84 (7/9)	1.14–3.76 (7/9)	A	3.62–4.84 (7/9)
SHc	Knives	S5	A	A	1.54–4.66 (9/9)	2.14–4.80 (9/9)	NA	5.14–7.84 (9/9)
		S6	A	P (1/9)	2.02–3.39 (9/9)	1.84–3.46 (8/9)	NA	4.24–7.80 (9/9)
		S7	A	P (1/9)	1.54–4.72 (9/9)	2.50–4.90 (9/9)	NA	5.62–8.39 (9/9)
	Hands	S8	NA	NA	2.32–3.74 (9/9)	1.84–3.84 (9/9)	A	4.84–7.14 (9/9)
		S9	NA	NA	1.84–3.02 (9/9)	1.14–3.54 (7/9)	A	3.54–5.92 (9/9)
		S10	NA	NA	1.84–3.50 (9/9)	1.99–3.80 (9/9)	P (1/9)	4.46–6.54 (9/9)
Total SH			0/81	2/81	130/162	123/162	1/81	143/162
PR	Work tables	P4	A	A	ND–0.92 (1/9)	ND–0.86 (1/9)	NA	ND–3.32 (1/9)
		P5	A	A	ND–1.31 (1/9)	ND–2.94 (4/9)	NA	2.16–3.68 (8/9)
		P6	A	A	ND–1.79 (2/9)	ND–2.20 (0/9)	NA	2.68–3.84 (3/9)
	Hands	P7	NA	NA	ND–2.00 (3/9)	ND–2.59 (3/9)	A	1.06–3.59 (5/9)
		P8	NA	NA	ND–1.12 (1/9)	ND–2.78 (1/9)	A	1.78–3.71 (8/9)
		P9	NA	NA	ND–2.91 (1/9)	ND–3.05 (1/9)	A	1.06–2.95 (0/9)
Total PR			0/27	0/27	9/54	10/54	0/27	25/54
BHa	Table	B3	A	A	ND	ND	NA	ND–2.63 (0/9)
	Knife	B4	A	A	ND	ND	NA	ND–3.38 (0/9)
	Grading machine	B5	A	A	ND	ND–0.72 (3/9)	NA	1.12–4.35 (1/9)
	Apron	B6	A	A	ND	ND	NA	ND–2.79 (0/9)
	Hands	B7	NA	NA	ND	ND	A	ND–2.49 (0/9)
BHb	Table	B3	A	A	ND	ND–1.18 (2/9)	NA	1.20–3.68 (0/9)
	Knife	B4	A	A	ND	ND–1.43 (2/9)	NA	ND–3.70 (0/9)
	Grading machine	B5	A	A	ND	ND	NA	1.60–4.06 (0/9)
	Apron	B6	A	A	ND	ND–1.12 (1/9)	NA	ND–2.62 (0/9)
	Hands	B7	NA	NA	ND	ND	A	ND–2.24 (0/9)
BHc	Table	B3	A	A	ND	ND–0.30 (0/9)	NA	2.30–3.37 (0/9)
	Knife	B4	A	A	ND	ND–0.05 (0/9)	NA	ND–2.48 (0/9)
	Grading machine	B5	A	A	ND	ND–1.24 (3/9)	NA	2.29–4.78 (2/9)
	Apron	B6	A	A	ND	ND	NA	ND–1.21 (0/9)
	Hands	B7	NA	NA	ND	ND	A	ND–2.32 (0/9)
BHd	Table	B3	A	A	ND	ND–2.53 (1/9)	NA	ND–4.68 (3/9)
	Knife	B4	A	A	ND	ND–1.94 (1/9)	NA	ND–5.50 (3/9)
	Grading machine	B5	A	A	ND	ND–2.35 (2/9)	NA	1.64–4.14 (1/9)
	Apron	B6	A	A	ND	ND–0.20 (0/9)	NA	ND–4.22 (1/9)
	Hands	B7	NA	NA	ND	ND–0.35 (0/9)	A	ND–3.36 (0/9)
BHe	Table	B3	A	A	ND	ND–1.37 (2/9)	NA	1.00–4.05 (0/9)
	Knife	B4	A	A	ND	ND–0.70 (0/9)	NA	ND–4.42 (0/9)
	Grading machine	B5	A	A	ND	ND–0.38 (0/9)	NA	1.64–4.14 (0/9)
	Apron	B6	A	A	ND	ND–1.67 (1/9)	NA	ND–3.15 (0/9)
	Hands	B7	NA	NA	ND	ND	A	ND–1.39 (0/9)
Total BH			0/180	0/180	0/225	18/225	0/45	11/225

[a] Values are range of microbial contamination (log CFU per square centimeter) followed by the number of samples exceeding the limit/number of samples taken. A, absent in 25 cm^2; ND, not detected (below the quantification limit of 1 log CFU/cm^2); NA, parameter not analyzed for this CSL; P, present in 25 cm^2.

[b] CSL, critical sampling location.

[c] AMP, aerobic mesophilic plate count.

from the environmental samples taken in the slaughterhouses are probably a result of inadequate cleaning programs *(17),* variability in temperature *(21),* and/or poor compliance with cleaning procedures, given the high contamination levels inherent in the slaughterhouse production areas *(39).* Likewise, as suggested by other authors *(18, 42),* the counts found in the processing plant, although much lower than those in the slaughterhouse, could be a result of cross-contamination between equipment, food contact surfaces, and/or the hands of food operators. In contrast, the contamination routes in butcher shops appear to be different. Lower microbial contamination levels were found overall, and *E. coli* was not detected in any of the environmental samples taken at any of the butcher shop CSLs. Therefore, the contamination in the meat samples in butcher shops probably is not due to cross-contamination from the environment but to the fact that competitive native microorganisms present in the lamb meat could growth under the specific conditions found in such shops. Various authors have found that psychrotrophic bacteria such as *Pseudomonas* grow actively during refrigeration and are chiefly responsible for product deterioration, whereas growth of *Enterobacteriaceae* and *E. coli* is reduced by low temperatures and bacterial competition *(7, 13, 35, 46).*

The microbiological safety level profiles constructed for the various establishments along the lamb production chain ranged from 9 to 17 (of a possible maximum of 18). All establishments therefore could improve the microbiological protocols in their FSMSs. The hide removal and evisceration steps in the slaughterhouses appear to be the most vulnerable and should therefore receive special attention when trying to improve the microbial control outcomes of FSMSs implemented at these sites. Microbial status can be improved by upgrading the design and/or current operation of the distinct control strategies in an FSMS (i.e., preventive measures, intervention processes, and monitoring systems) *(39, 40).* However, in practice, most intervention methods to reduce microbial contamination (decontamination or irradiation) are currently prohibited by European legislation; only steam pasteurization is currently permitted in Europe *(14).* Microbial food safety along the lamb production chain therefore depends mainly on preventive measures, such as dedicated cleaning and disinfection programs, extensive personal hygiene requirements, advanced hygiene equipment and facilities, strict control of daily compliance with safety and hygiene procedures, and systematic verification of the preventive measures *(39–41).* Enhancing the competence and skill of both managers and operators by appropriate and regular training may improve microbiological status of these facilities by supporting correct hygienic practices *(40, 50).*

The MAS was used to perform a systematic analysis of the microbiological protocols of FSMSs implemented along the lamb production chain. This analysis provided a coherent view of the dynamic behavior of microbial contaminants along the lamb production chain and demonstrated the interdependence between the various steps along the chain. The microbial dynamics also highlight the limited possibilities available for the application of effective microbiological control measures in such a fresh meat chain. The MAS is a useful tool for assessing the actual performance of microbial control measures implemented in FSMSs along the (lamb) production chain because it provides information about the FSMS performance in an effective and efficient way.

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REFERENCES

1. Aarnisalo, K., K. Tallavaara, G. Wirtanen, R. Maijala, and L. Raaska. 2006. The hygienic working practices of maintenance personnel and equipment hygiene in the Finnish food industry. *Food Control* 12: 1001–1011.
2. Alzamora, S. M., M. S. Tapia, A. López-Malo, and J. Welti-Chanes. 2003. The control of water activity, p. 139–167. *In* P. Zeuthen and L. Bogh-Sorensen (ed.), Food preservation techniques. CRC Press, Boca Raton, FL.
3. Anonymous. 2001. Commission Decision 2001/471/EC (8 June 2001) laying down rules for the regular checks on the general hygiene carried out by the operators in establishments according to Directive 64/433/EEC on health conditions for the production and marketing of fresh meat and Directive 71/118/EEC on health problems affecting the production and placing on the market of fresh poultry meat. *Off. J. Eur. Communities* L 165:48–53.
4. Anonymous. 2005. Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. (Amended by Commission Regulation (EC) No 1441/2007 of 5 December 2007.) *Off. J. Eur. Union* L 338:1–26.
5. Arthur, T. M., J. M. Bosilevac, X. Nou, S. D. Shackelford, T. L. Wheeler, M. P. Kent, D. Jaroni, B. Pauling, D. M. Allen, and M. Koohmaraie. 2004. *Escherichia coli* O157 prevalence and enumeration of aerobic bacteria, *Enterobacteriaceae,* and *Escherichia coli* O157 at various steps in commercial beef processing plants. *J. Food Prot.* 67:658–665.
6. Barkocy-Gallagher, G. A., T. M. Arthur, M. Rivera-Betancourt, X. Nou, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2003. Seasonal prevalence of Shiga toxin–producing *Escherichia coli,* including O157:H7 and non-O157 serotypes, and *Salmonella* in commercial beef processing plants. *J. Food Prot.* 66:1978–1986.
7. Barrera, O., J. M. Rodríguez-Calleja, J. A. Santos, A. Otero, and M. L. García-López. 2007. Effect of different storage conditions on *E. coli* O157:H7 and the indigenous bacterial microflora on lamb meat. *Int. J. Food Microbiol.* 115:244–251.
8. Barros, M. D. A. F., L. A. Nero, A. A. Monteiro, and V. Beloti. 2007. Identification of main contamination points by hygiene indicator microorganisms in beef processing plants. *Ciênc. Tecnol. Aliment.* 27: 856–862.
9. Battisti, A., S. Lovari, A. Franco, A. Di Egidio, R. Tozzoli, A. Caprioli, and S. Morabito. 2006. Prevalence of *Escherichia coli* O157 in lambs at slaughter in Rome, central Italy. *Epidemiol. Infect.* 134: 415–419.
10. Blanco, M., J. E. Blanco, A. Mora, J. Rey, J. M. Alonso, M. Hermoso, M. P. Alonso, G. Dahbi, E. A. González, M. I. Bernárdez, and J. Blanco. 2003. Serotypes, virulence genes, and intimin types of Shiga toxin (verotoxin)–producing *Escherichia coli* isolates from healthy sheep in Spain. *J. Clin. Microbiol.* 41:1351–1356.
11. Bosilevac, J. M., T. M. Arthur, T. L. Wheeler, S. D. Shackelford, M. Rossman, J. O. Reagan, and M. Koohmaraie. 2004. Prevalence of *Escherichia coli* O157 and levels of aerobic bacteria and *Enterobacteriaceae* are reduced when hides are washed and treated with

cetylpyridinium chloride at a commercial beef processing plant. *J. Food Prot.* 67:646–650.
12. Capita, R., M. Prieto, and C. Alonso-Calleja. 2004. Sampling methods for microbiological analysis of red meat and poultry carcasses. *J. Food Prot.* 67:1303–1308.
13. Dainty, R. H., and B. M. Mackey. 1992. The relationship between the phenotypic properties of bacteria from chill-stored meat and spoilage processes. *J. Appl. Bacteriol.* 21(Symp. Suppl.):103S–114S.
14. Duffy, G. 2006. Emerging pathogenic *E. coli*, p. 253–281. *In* Y. Motarjemi and M. Adams (ed.), Emerging food-borne pathogens. Woodhead Publishing Limited, Cambridge.
15. Erdogrul, Ö. 2005. Microbiological properties of boneless sheep meat in Kahramanmaras. *Turk. J. Vet. Anim. Sci.* 29:145–150.
16. European Food Safety Authority. 2009. The community summary report on food-borne outbreaks in the European Union in 2007. *EFSA J.* 271.
17. Gill, C. O., M. Badoni, and J. C. McGinnis. 1999. Assessment of the adequacy of cleaning of equipment used for breaking beef carcasses. *Int. J. Food Microbiol.* 46:1–8.
18. Gill, C. O., J. C. McGinnis, and J. Bryant. 2001. Contamination of beef chucks with *Escherichia coli* during carcass breaking. *J. Food Prot.* 64:1824–1827.
19. Gobat, P. F., and T. Jemmi. 1991. Epidemiological studies on *Listeria* sp. in slaughterhouses. *Fleischwirtschaft Int.* 1:44–49.
20. Gorraiz, C., M. J. Beriain, J. Chasco, and M. Iraizoz. 2000. Descriptive analysis of meat from young ruminants in Mediterranean systems. *J. Sens. Stud.* 15:137–150.
21. Huis in't Veld, J. H. J. 1996. Microbial and biochemical spoilage of foods: an overview. *Int. J. Food Microbiol.* 33:1–18.
22. International Organization for Standardization. 1996. Microbiology of food and animal feeding stuffs—horizontal method for the detection and enumeration of *Listeria monocytogenes*. Part 1. Detection method (ISO 11290-1:1996/Amd 1:2004). International Organization for Standardization, Geneva.
23. International Organization for Standardization. 1998. Microbiology of food and animal feeding stuffs—horizontal method for the detection and enumeration of *Listeria monocytogenes*. Part 2. Enumeration method (ISO 11290-2:1998/Amd 1:2004). International Organization for Standardization, Geneva.
24. International Organization for Standardization. 2001. Microbiology of food and animal feeding stuffs—horizontal method for the enumeration of β-glucuronidase positive *Escherichia coli*. Part 2. Colony-count technique at 44°C using 5-bromo-4-chloro-3-indolyl β-D-glucuronide (ISO 16649-2:2001). International Organization for Standardization, Geneva.
25. International Organization for Standardization. 2002. Microbiology of food and animal feeding stuffs—horizontal method for the detection of *Salmonella* spp. (ISO 6579:2002). International Organization for Standardization, Geneva.
26. International Organization for Standardization. 2003. Microbiology of food and animal feeding stuffs—carcass sampling for microbiological analysis (ISO 17604:2003). International Organization for Standardization, Geneva.
27. International Organization for Standardization. 2003. Microbiology of food and animal feeding stuffs—preparation of test samples, initial suspension and decimal dilutions for microbiological examination (ISO 6887-2:2003). International Organization for Standardization, Geneva.
28. International Organization for Standardization. 2003. Microbiology of food and animal feeding stuffs—horizontal method for the enumeration of microorganisms, colony count technique at 30°C (ISO 4833:2003). International Organization for Standardization, Geneva.
29. International Organization for Standardization. 2003. Microbiology of food and animal feeding stuffs—horizontal method for the enumeration of coagulase positive *Staphylococcus aureus* and other species. Part 1. Technique using Baird-Parker agar medium. Amendment 1. Inclusion of precision data (ISO 6888-1:1999/Amd. 1:2003). International Organization for Standardization, Geneva.
30. International Organization for Standardization. 2004. Microbiology of food and animal feeding stuffs—horizontal method for sampling techniques from surfaces using contact plates and swabs (ISO 18593:2004). International Organization for Standardization, Geneva.
31. International Organization for Standardization. 2004. Microbiology of food and animal feeding stuffs—horizontal method for the detection and enumeration of *Enterobacteriaceae*. Part 2. Colony-count method (ISO 21528-2:2004). International Organization for Standardization, Geneva.
32. Jacxsens, L., J. Kussaga, P. A. Luning, M. Van der Spiegel, F. Devlieghere, and M. Uyttendaele. 2009. A microbial assessment scheme to measure microbial performance of food safety management systems. *Int. J. Food Microbiol.* 134:113–125.
33. Kalchayanand, N., T. M. Arthur, J. M. Bosilevac, D. M. Brichta-Harhay, M. N. Guerini, S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2007. Microbiological characterization of lamb carcasses at commercial processing plants in the United States. *J. Food Prot.* 70:1811–1819.
34. Koohmaraie, M., T. M. Arthur, J. M. Bosilevac, D. M. Brichta-Harhay, N. Kalchayanand, S. D. Shackelford, and T. L. Wheeler. 2007. Interventions to reduce/eliminate *Escherichia coli* O157:H7 in ground beef. *Meat Sci.* 77:90–96.
35. Lambert, A. D., J. P. Smith, and K. L. Dodds. 1991. Shelf life extension and microbiological safety of fresh meat—a review. *Food Microbiol.* 8:267–297.
36. Lambert, D. M., and M. C. Cooper. 2000. Issues in supply chain management. *Ind. Market. Manag.* 29:65–83.
37. Lenahan, M., S. O'Brien, K. Kinsella, T. Sweeney, and J. J. Sheridan. 2007. Prevalence and molecular characterization of *Escherichia coli* O157:H7 on Irish lamb carcasses, fleece and in faeces samples. *J. Appl. Microbiol.* 103:2401–2409.
38. Little, C. L., J. F. Richardson, R. J. Owen, E. de Pinna, and E. J. Threlfall. 2008. *Campylobacter* and *Salmonella* in raw red meats in the United Kingdom: prevalence, characterization and antimicrobial resistance pattern, 2003–2005. *Food Microbiol.* 25:538–543.
39. Luning, P. A., L. Bango, J. Kussaga, J. Rovira, and W. J. Marcelis. 2008. Comprehensive analysis and differentiated assessment of food safety control systems: a diagnostic instrument. *Trends Food Sci. Technol.* 19:522–534.
40. Luning, P. A., L. Jacxsens, J. Rovira, S. M. Osés, M. Uyttendaele, and W. J. Marcelis. 2011. A concurrent diagnosis of microbiological food safety output and food safety management system performance: cases from meat processing industries. *Food Control* 22:555–565.
41. Luning, P. A., W. J. Marcelis, J. Rovira, M. Van der Spiegel, M. Uyttendaele, and L. Jacxsens. 2009. Systematic assessment of core assurance activities in company specific food safety management systems. *Trends Food Sci. Technol.* 20:300–312.
42. McEvoy, J. M., J. J. Sheridan, I. S. Blair, and D. A. McDowell. 2004. Microbial contamination on beef in relation to hygiene assessment based on criteria used in EU Decision 2001/471/EC. *Int. J. Food Microbiol.* 92:217–225.
43. Mossel, D. A. A., J. E. L. Corry, C. B. Struijk, and R. M. Baird. 1995. Essentials of the microbiology of food. A textbook for advanced studies. John Wiley & Sons, Chichester, UK.
44. Nørrung, B., and S. Buncic. 2008. Microbial safety of meat in the European Union. *Meat Sci.* 78:14–24.
45. Nou, X., M. Rivera-Betancourt, J. M. Bosilevac, T. L. Wheeler, S. D. Shackelford, B. L. Gwartney, J. O. Reagan, and M. Koohmaraie. 2003. Effect of chemical dehairing on the prevalence of *Escherichia coli* O157:H7 and the levels of aerobic bacteria and *Enterobacteriaceae* on carcasses in a commercial beef processing plant. *J. Food Prot.* 66:2005–2009.
46. Prieto, M., M. L. García-López, M. R. García-Armesto, A. Otero, T. M. López, and B. Moreno. 1993. Factors affecting spoilage microflora succession on lamb carcasses at refrigeration temperatures. *J. Appl. Bacteriol.* 74:521–525.
47. Rajpura, A., K. Lamden, S. Forster, S. Clarke, J. Cheesbrough, S. Gornall, and S. Waterworth. 2003. Large outbreak of infection with *Escherichia coli* O157 PT21/28 in Eccleston, Lancashire, due to cross contamination at a butcher's counter. *Commun. Dis. Public Health* 6: 279–284.

48. Roberts, T. A., J. I. Pitt, J. Farkas, and F. H. Grau. 2001. Carne y productos cárnicos, p. 1–68. *In* International Commission on Microbiological Specifications for Foods (ed.), Microorganismos de los alimentos, vol. 6. Ecología microbiana de los productos alimentarios. Editorial Acribia S.A., Zaragoza, Spain.
49. Sampers, I., L. Jacxsens, P. A. Luning, W. J. Marcelis, A. Dumoulin, and M. Uyttendaele. 2010. Performance of food safety management systems in poultry meat preparation processing plants in relation to *Campylobacter* spp. contamination. *J. Food Prot.* 73:1447–1457.
50. Seaman, P. 2010. Food hygiene training: introducing the food hygiene training model. *Food Control* 21:381–387.
51. Sharma, C. S., J. P. S. Gill, R. S. Aulakh, S. K. Bedi, and J. K. Sharma. 2007. Isolation of enteropathogens of zoonotic significance from butchers' hands and equipment. *Indian J. Anim. Sci.* 77:151–153.
52. Small, A., C. James, S. James, R. Davies, E. Liebana, M. Howell, M. Hutchison, and S. Buncic. 2006. Presence of *Salmonella* in the red meat abattoir lairage after routine cleansing and disinfection and on carcasses. *J. Food Prot.* 69:2342–2351.
53. Small, A., C. A. Reid, S. M. Avery, N. Karabasil, C. Crowley, and S. Buncic. 2002. Potential for the spread of *Escherichia coli* O157, *Salmonella,* and *Campylobacter* in the lairage environment at abattoirs. *J. Food Prot.* 65:931–936.
54. Sperber, W. H. 2005. HACCP does not work from farm to table. *Food Control* 16:511–514.
55. Sumner, J., E. Petrenas, P. Dean, P. Dowsett, G. West, R. Wiering, and G. Raven. 2003. Microbial contamination on beef and sheep carcasses in South Australia. *Int. J. Food Microbiol.* 81:255–260.
56. Uyttendaele, M., L. Jacxsens, A. De Loy-Hendrickx, F. Devlieghere, and J. Debevere. 2010. Microbiologische richtwaarden en wettelijke microbiologische criteria, juli 2010 [Microbiological guideline values and legal microbiological criteria, July 2010]. Laboratory of Food Microbiology and Food Preservation, Ghent University, Ghent, Belgium.
57. Worsfold, D., and C. J. Griffith. 2001. An assessment of cleaning regimes and standards in butchers' shops. *Int. J. Environ. Health Res.* 11:245–256.