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Ratio between carcass-and skin-microflora as an abattoir process hygiene indicator

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ABSTRACT

In two abattoirs, each slaughtering both cattle and pigs, 100 cattle and 100 pigs were randomly selected and sampled. From each animal, two samples were taken: a) immediately after sticking of bovines or stunning of pigs, approximately 2000 cm^2 hide (cattle) or 1500 cm^2 skin (pigs) areas were sponge-swabbed; and b) at the end of slaughter line but before chilling, the same areas on corresponding dressed carcasses were sponge-swabbed. In each swab-sample (400 in total), total viable count (TVC) and *Enterobacteriaceae* count (EC), as well as *Escherichia coli* O157 (in cattle) or *Salmonella* (in pigs) occurrence, were determined and used to assess process hygiene in the abattoirs. The results indicated that simply fitting mean TVC and/or EC on final carcasses into an acceptable, marginal or unacceptable process hygiene category (according to current microbiological EU process hygiene criteria) did not enable characterisation of each process with respect to its ability to reduce the transfer of incoming microbial loads (i.e. on skins) onto dressed carcasses. On the other hand, determining the ratio between mean TVC and/or EC on final carcasses and those on corresponding skins enabled more precise assessment of the hygiene of each abattoir process, as well as more reliable differentiation between abattoirs. On the other hand, occurrence of *E. coli* O157 in cattle or *Salmonella* in pigs (skins and/or carcasses), being dependant on varying factors including those on-farm/pre-abattoir, did not appear to be very useful for characterisation of the process hygiene but is valuable for the purposes of consumer exposure assessment and pathogen reduction.

1. Introduction

Criteria set by national and international authorities have often been based upon experience of food production and processing, research and expert opinions of what was considered achievable in relation to the application of good hygienic practices on one hand, and what was necessary to ensure food safety on the other (EFSA, 2007).

The European Commission recently adopted the new regulation (EC 2073/2005; EC 1441/2007) on microbiological criteria for foodstuffs. That regulation introduces two different types of criteria; *Food Safety Criteria* and *Process Hygiene Criteria*. An EU *Food Safety Criterion* defines the acceptability of food products placed on the market; if the criterion is not met, the product/batch has to be withdrawn from the market. An EU *Process Hygiene Criterion* (PHC) is an indicator of the acceptable functioning of Hazard Analysis and Critical Control Points system-based manufacturing, handling and distribution processes, so is applicable at the process level. It sets an indicative contamination value above which corrective actions are required; if the criterion is not met, the process has to be reviewed and improved.

However, when the set PHC's contamination values are applicable solely to the product at the end of the manufacturing process, the nature of the PHC is actually similar to that of so-called "end-product" criteria (EFSA, 2007). In other words, such a PHC cannot actually distinguish between more or less hygienic production processes within each category of satisfactory, marginal or unsatisfactory (i.e. between those with higher or with lower initial/incoming contamination *versus* final contamination ratios), but implicitly considers all production processes with equal final contamination values as equally hygienic (EFSA, 2007).

This shortcoming in assessing red meat abattoir process hygiene had been recognised earlier, so characterisation of the process by analyzing microbial loads at multiple stages was advocated (Bolton, Sheridan, & Doherty, 2000; Gill & Jones, 1997), but the several-stages approach involves laborious sampling plans. Subsequently, a simplified approach to better characterisation of cattle abattoir process *via* microbiological comparison of the final carcasses with

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the main source of incoming contamination – skins – was proposed (Vivas Alegre & Buncic, 2004). This was based on recognition that direct faecal contamination (leakage/spillage from guts onto the meat) in modern abattoirs is relatively rare, whilst contamination from the hides (*via* contact, hands/tools and/or airborne) is a key and common event (Antic et al., 2010a, 2010b; Koohmaraie et al., 2005; Nastasijevic, Mitrovic, & Buncic, 2008; Small, Wells-Burr, & Buncic, 2004). In the study (Vivas Alegre & Buncic, 2004) using cattle with hides inoculated with a marker organism, the efficacy of the abattoir process in reducing incoming contamination was assessed through determining the ratio between the marker's counts on final carcasses and those on hides (Vivas Alegre & Buncic, 2004). However, no studies on the use of the ratio between natural hide microflora and final carcass microflora for PHC purposes in cattle abattoirs have been published to date.

In pig abattoir operations, the effects of skin microflora on the microbial status of final carcasses are less direct/clear than in cattle slaughter. This is mainly due to the interference of repeated changes of skin microflora which regularly occur during several successive steps, including: scalding decreases bacterial counts on the skin, after which dehairing increases them, singeing then decreases them, polishing then increases them and, finally, washing decreases them. Nevertheless, it has been demonstrated that foodborne pathogens such as *Salmonella* can be found both on the skin of pigs entering the slaughter line and the final carcasses (Davies, McLaren, & Bedford, 1999), and that carcass contamination can be directly linked to the skin contamination of live pigs before stunning (Rossel, Jouffe, & Beloeil, 2009). In the latter study, the conditional probability of carcass surface contamination decreased from 59 to 35%, depending on whether the skin was contaminated or not. However, no studies on the use of the ratio between pre-scalding skin microflora and corresponding final carcass microflora as a PHC for pig abattoirs have been published to date.

Therefore, the main objectives of present study were to: a) determine the microbiological relationship between skins and corresponding final carcasses in commercial cattle and pig abattoirs; and b) consider the potential of that relationship as a process hygiene criterion.

2. Materials and methods

2.1. Animals and abattoirs

In two commercial abattoirs, each slaughtering cattle as well as pigs, skins and carcasses of 100 randomly selected cattle (50 per abattoir) and 100 randomly selected pigs (50 per abattoir) were sampled (400 samples in total). Samples from cattle were taken during 5 visits per abattoir during spring and summer; and from pigs during 3 visits per abattoir during winter.

2.2. Sampling of bovine hides and carcasses

Plain cellulose washing-up sponges (10 × 10 cm; 4 cm thickness) containing no antimicrobial additives were exposed to UV light for 15 min and then wrapped in aluminum foil. Just before sampling, sponges were moistened with 10 ml of sterile Maximum Recovery Diluent (MRD; Oxoid, Hampshire, England, UK). From each bovine, two swab-samples were taken: a) after sticking but before dehiding of bovines, approximately 2000 cm^2 of hide area (lateral rump-perianal-medial rump-flank-brisket-neck) was swabbed; and b) at the end of the slaughter line but before chilling, the same area on the corresponding dressed carcass was swabbed. Each swab was placed in a separate stomacher bag (Nasco, Whirl-pack, 19 × 30 cm; Fort Atkinson, WI, USA) and transported in a chill-bin to the laboratory within 2 h.

2.3. Sampling of porcine skin and carcasses

Swabs were prepared as described for bovines. From each porcine, two samples were taken: a) after stunning but before sticking of pigs, approximately 1500 cm^2 of skin area (lateral ham-perianal-medial ham-belly-jowl) was swabbed on the left side; and b) at the end of slaughter line but before chilling, the same area on the right side of the corresponding carcass was swabbed. Each swab was the handled as described for bovines.

2.4. Homogenization of samples

Maximum Recovery Diluent (MRD; Oxoid; 90 ml) was added to each bag containing a sponge-swab, the bag exterior was then repeatedly squeezed manually for 1 min and further decimal dilutions were made in MRD (ISO method 6887-1:1999). Sample homogenates or their appropriate dilutions were used for microbiological analysis as indicated below.

2.5. Determination of total viable count (TVC) and Enterobacteriaceae count (EC)

For TVC, 1 ml volumes from appropriate sample dilutions were spread onto Aerobic Count Plate Petrifilms (3 M Health Care, St. Paul, USA), incubated at 30 °C for 72 h and the colonies counted (AFNOR validated method 3 M 01/1-09/89). For EC, one ml volumes from appropriate dilutions were spread onto *Enterobacteriaceae* count plates Petrifilms (3 M Health Care), incubated at 37 °C for 24 h and typical colonies were counted (AFNOR validated method 3 M 01/06 09/97).

2.6. Detection of Escherichia coli O157

From each sample homogenate, 25 ml volume was transferred to 225 ml of enrichment medium (mEC + Novobiocin selective enrichment broth; Merck, Darmstadt, Germany), incubated at 37 °C for 24 h, followed by detection of *E. coli* O157 by using an immunochromatographic rapid test (Singlepath® E. coli O157; Merck). According to the manufacturer's manual, this *E. coli* O157 rapid test is AOAC validated, with a detection limit of 1 CFU/25 g sample and both sensitivity and specificity of >99%.

2.7. Detection of Salmonella

ISO 6579:2002 method was followed. Briefly, each sample was incubated in buffered peptone water (BPW; Oxoid) for 18 h at 37 °C (pre-enrichment step). Subsequently, 1 ml was transferred to 10 ml of Muller Kauffmann tetrathionate-novobiocin broth (MKTTn, Oxoid, Hampshire, England, UK) and 0.1 ml was transferred to 10 ml of Rappaport Vassiliadis Broth with soya (RVS, Oxoid) and incubated at 37 °C and 41.5 °C, respectively, for 24 h (enrichment step). Then, both xylose lysine deoxycholate agar (XLDA, Oxoid) and *Salmonella* Chromogenic agar (SHA, Oxoid) plates were inoculated from RVS broth. Also, both brilliant green agar (BGA, Oxoid) and XLDA plates were inoculated from MKTTn broth. All the plates were incubated at 37 °C for 24 h. Suspect colonies (with black centre and/or pink from XLDA, pink from BGA or magenta from SHA) were purified on a nutrient agar and confirmed biochemically using API 20E kits (BioMérieux, France) and serologically using poly O antiserum (Pro-Lab Diagnostics, Canada).

2.8. Analysis of results

On both skins and carcasses in both cattle and pigs, TVC and EC were calculated as CFU/cm^2. The formula for calculating carcass *versus* hide/skin either TVC ratio or EC ratio is given below.

Table 1
Microflora on bovine hides and correlated dressed carcasses.

Microorganisms	Abattoir (number of animals tested)	Hide	Dressed carcass
Geometric mean of Total Viable count, TVC: CFU/cm^2 (max–min)	A (50)	1.08×10^8 (A) (1.65×10^{10}–1.86×10^6)	1.26×10^4 (B) (6.92×10^5–4.79×10^2)
	B (50)	8.28×10^7 (A) (3.89×10^9–1.45×10^6)	1.42×10^3 (C) (3.63×10^4–1.58×10^2)
Geometric mean of *Enterobacteriaceae* count: mean CFU/cm^2 (max–min)	A (50)	1.97×10^2 (D) (8.13×10^4–0.15×10^1)	1.06×10^1 (E) (1.48×10^3–0.11×10^1)
	B (50)	2.92×10^2 (D) (4.27×10^3–3.02×10^1)	0.59×10^1 (E) (3.09×10^2–0.02×10^1)
Escherichia coli O157 occurrence (%)	A (50)	52	12
	B (50)	64	14

(A, B, C, D, E) Values marked with different letters within the same column are significantly different, $p < 0.05$.

$$\text{Carcass } \textit{versus} \text{ hide/skin ratio (\%)} = \frac{\sqrt[n]{x_1 \cdot x_2 \cdot \cdots \cdot x_n}(\text{carcass})}{\sqrt[n]{x_1 \cdot x_2 \cdot \cdots \cdot x_n}(\text{hide/skin})} \cdot 100 \quad (1)$$

where x is either TVC or EC (CFU/cm^2).

Where appropriate, the TVC or EC values were first converted into log CFU/cm^2 and used to calculate mean values and significance of difference between them (*T*-test; as commonly used in meat industry) for each animal species and each abattoir.

E. coli O157 on hides/carcasses of bovines and *Salmonella* on skins/carcasses of pigs were expressed as occurrence (i.e. present/absent).

3. Results

3.1. Cattle abattoirs

3.1.1. Microbial loads on bovine hides and carcasses

Levels of general microflora (TVC and EC) on bovine hides and dressed carcasses in two cattle abattoirs are shown in Table 1. Although mean TVC on hides did not differ significantly between abattoirs, the mean TVC on dressed carcasses was lower in abattoir B than in A. On the other hand, mean EC did not differ significantly between abattoirs – either on hides or on dressed carcasses.

E. coli O157 was present on the hides of 52% and 64%, and on the dressed carcasses of 12% and 14% bovines in abattoirs A and B, respectively (Table 1). These occurrences can be considered as relatively high and, from a practical perspective, not markedly different.

3.1.2. Application of the EU process hygiene criteria

When TVC-related EU process hygiene criteria (<3.5 log CFU/cm^2 for acceptable, 3.5–5.0 log CFU/cm^2 for marginal and >5.0 log CFU/cm^2 for unacceptable ranges) were applied to the mean bovine carcass TVC values, abattoir A fell into the marginal and B into the acceptable range; so neither of the abattoir processes were unacceptable (Table 2). However, when individually considering the 50 carcasses tested in each abattoir, in abattoir A 17 carcasses fell into the acceptable, 26 carcasses into the marginal and 7 carcasses into the unacceptable categories; whilst in abattoir B, 38 carcasses fell into the acceptable, 12 carcasses into the marginal and no carcasses into the unacceptable categories. This indicated that the TVC-related EU process hygiene criteria based on daily mean log TVC value for carcasses only marginally distinguished between processes in abattoirs A and B, although the process in abattoir B was clearly more hygienic, as evidenced through comparison of individual carcasses.

When EC-related EU process hygiene criteria (<1.5 log CFU/cm^2 for acceptable, 1.5–2.5 log CFU/cm^2 for marginal and >2.5 log CFU/cm^2 for unacceptable ranges) were applied to the mean bovine carcass EC values, both abattoir A and B fell into the acceptable range (Table 2). However, when individually considering the 50 carcasses tested in each abattoir, in abattoir A, 38 carcasses fell into the acceptable, 10 carcasses into the marginal and 2 carcasses into the unacceptable categories; whilst in abattoir B, 47 carcasses fell into the acceptable, 3 carcasses into the marginal and no carcasses into the unacceptable categories. This indicated that the EC-related EU process hygiene criteria based on daily mean log EC value for carcasses did not distinguish between processes in abattoirs A and B (both were within the acceptable category), although the process in abattoir B was clearly more hygienic as evidenced through comparison of individual carcasses. Furthermore, when looking at abattoir A only, there was a disagreement between process hygiene assessments based on the EU TVC- and EC-related criteria, as the former indicated a marginal but the latter an acceptable category.

The *Salmonella* occurrence on dressed bovine carcasses, which is included in the EU process hygiene criteria (≤2 positive carcasses out of 50), was not determined in this study, because an our previous study failed to find *Salmonella* in bovines slaughtered in the same region in Serbia (Antic et al., 2010a).

3.1.3. Application of carcass microflora vs hide microflora ratio as process hygiene criteria

The mean TVC on dressed bovine carcasses in abattoir A was 0.0116% of the mean hide TVC on corresponding animals, whilst this value was 0.0017% in abattoir B (Table 2). In other words, abattoir B was roughly 6.8-fold more successful in reducing the transfer of incoming, hide-borne TVC contamination onto the resulting

Table 2
Process hygiene assessment of cattle abattoir operations.

Microorganisms	Criteria	Process hygiene assessment of cattle operation	
		Abattoir A	Abattoir B
Total viable count (TVC)	EU process hygiene criteria for dressed carcasses*	Marginal category	Acceptable category
	Carcass *vs* skin ratio**	0.0116%	0.0017%
Enterobacteriaceae count (EC)	EU process hygiene criteria for dressed carcasses*	Acceptable category	Acceptable category
	Carcass *vs* skin ratio**	5.39%	2.00%
E. coli O157	EU process hygiene criteria for dressed carcasses	N/A	N/A
	Carcass occurrence as % of hide occurrence	23.1%	21.8%

N/A Not applicable; *The EU criteria are based on use of excision-sampling method. Swab-sampling method is also allowed by the same regulation, predominantly is used by the meat industry, and also was used in this study, but no "conversion factor" between results obtained by excision and swabbing are provided in the regulation. **Formula is shown in Materials and Methods section.

Table 3
Microflora on porcine skins and correlated dressed carcasses.

Microorganisms	Abattoir (number of animals tested)	Skin	Dressed carcass
Geometric mean of Total Viable count, TVC: CFU/cm^2 (max–min)	A (50)	9.28×10^6 (A) (4.17×10^9–1.54×10^5)	1.24×10^4 (C) (7.08×10^5–3.09×10^2)
	B (50)	2.87×10^7 (B) (1.54×10^9–1.32×10^5)	1.97×10^3 (D) (6.61×10^5–2.29×10^2)
Geometric mean of *Enterobacteriaceae* count: mean CFU/cm^2 (max–min)	A (50)	7.78×10^3 (E) (1.62×10^5–5.37×10^1)	8.94×10^1 (F) (1.41×10^3–0.63×10^1)
	B (50)	4.19×10^3 (E) (2.04×10^5–4.68×10^1)	0.97×10^1 (G) (9.55×10^2–0.09×10^1)
Salmonella occurrence (%)	A (50)	28	14
	B (50)	40	14

(A, B, C, D, E, F, G) Values marked with different letters within the same column are significantly different, $p < 0.05$.

carcasses. The mean EC on dressed bovine carcasses in abattoir A was 5.39% of the mean hide EC on corresponding animals, whilst the value was 2.00% in abattoir B (Table 2). In other words, abattoir B was roughly 2.7-fold more successful in reducing transfer of incoming, hide-borne EC contamination onto the resulting carcasses. Therefore, both the TVC- and EC-relationship between carcass and hide microflora in corresponding bovines indicated that the process in abattoir B was markedly more hygienic, compared with abattoir A. This is in contrast to the fact that, as shown above, processes in the two abattoirs were either only marginally distinguishable (*via* TVC) or indistinguishable (*via* EC) when using the EU process hygiene criteria solely based on the mean values of dressed carcasses.

The *E. coli* O157 occurrence on dressed bovine carcasses in abattoir A represented roughly 23% of the occurrence on the hides of corresponding animals, whilst this value was roughly 22% in abattoir B (Table 2). In other words, both abattoir A and B reduced, to a similar extent, transfer of incoming *E. coli* O157 hide-borne contamination onto the resulting carcasses. This is opposite to the finding based on TVC- and EC-related carcass–hide relationships showing that abattoir B was clearly more hygienic than abattoir A (Table 2).

3.2. Pig abattoirs

3.2.1. Microbial loads on porcine skins and dressed carcasses

Levels of general microflora (TVC and EC) on porcine skins and dressed carcasses in two pig abattoirs are shown in Table 3. Although the mean TVC on pig skins in abattoir A was lower than in abattoir B, the mean TVC on dressed carcasses had a different trend: it was higher in abattoir A than in B. On the other hand, although the mean EC on skins did not differ significantly between abattoirs, it was higher on dressed carcasses in abattoir A than in B.

Salmonella was present on the skins of 28% and 40% in abattoir A and B, respectively, and on the dressed carcasses of 14% porcines in both abattoirs (Table 3). These occurrences can be considered as relatively high.

3.2.2. Application of the EU process hygiene criteria

When TVC-related EU process hygiene criteria (<4.0 log CFU/cm^2 for acceptable, 4.0–5.0 log CFU/cm^2 for marginal and >5.0 log CFU/cm^2 for unacceptable ranges) were applied to the mean porcine carcass TVC values, abattoir A fell into the marginal and B into the acceptable categories; therefore, neither of the abattoir processes were unacceptable (Table 4). However, when individually considering the 50 carcasses tested in each abattoir, in abattoir A, only 25 carcasses fell into the acceptable, 19 carcasses into the marginal and 6 carcasses into the unacceptable categories; whilst in abattoir B, 44 carcasses fell into the acceptable, 4 carcasses into the marginal and 2 carcasses into the unacceptable categories. This indicates that the TVC-related EU process hygiene criteria based on daily mean log TVC value for carcasses only marginally distinguished between processes in abattoirs A and B, but neither was unacceptable. However, the process in abattoir B was clearly more hygienic as evidenced through comparison of individual carcasses.

When EC-related EU process hygiene criteria (<2.0 log CFU/cm^2 for acceptable, 2.0–3.0 log CFU/cm^2 for marginal and >3.0 log CFU/cm^2 for unacceptable ranges) were applied to the mean porcine carcass EC values, both abattoir A and B fell into the acceptable range (Table 4). However, when individually considering the 50 carcasses tested in each abattoir, in abattoir A, 28 carcasses fell into the acceptable, 16 carcasses into the marginal and 6 carcasses into the unacceptable categories; whilst in abattoir B, 45 carcasses fell into the acceptable, 5 carcasses into the marginal and no carcasses into the unacceptable categories. This indicate that the EC-related EU process hygiene criteria based on daily mean log EC value for carcasses did not globally distinguish between processes in abattoirs A and B (both were within the acceptable category), although the process in abattoir B was clearly more hygienic as evidenced through comparison of individual carcasses. Furthermore, when looking at abattoir A only, there was a disagreement between process hygiene assessments based on the EU TVC- and EC-related criteria, as the former indicated a marginal but the latter an acceptable category.

The *Salmonella* occurrence on dressed porcine carcasses, as the EU process hygiene criteria (≤5 positive carcasses out of 50), indicated that process hygiene was the same and unacceptable in both abattoir A and B (i.e. 14% out of 50 in each; Table 4). This is in disagreement with process hygiene assessments of abattoirs A and B based on the EU TVC- and EC-related criteria (indicated above) which did not show their unacceptability.

Table 4
Process hygiene assessment of pig abattoir operations.

Microorganisms	Criteria	Process hygiene assessment of pigs operation	
		Abattoir A	Abattoir B
Total viable count (TVC)	EU process hygiene criteria for dressed carcasses*	Marginal category	Acceptable category
	Carcass *vs* skin ratio**	0.134%	0.0069%
Enterobacteriaceae count (EC)	EU process hygiene criteria for dressed carcasses*	Acceptable category	Acceptable category
	Carcass *vs* skin ratio**	1.15%	0.23%
Salmonella	EU process hygiene criteria for dressed carcasses*	Unacceptable category	Unacceptable category
	Carcass occurrence as % of hide occurrence	50.0%	35.0%

N/A Not applicable; *The EU criteria are based on use of excision-sampling method. Swab-sampling method is also allowed by the same regulation, predominantly is used by the meat industry, and also was used in this study, but no "conversion factor" between results obtained by excision and swabbing are provided in the regulation. **Formula is shown in Materials and Methods section.

3.2.3. Application of carcass microflora vs skin microflora ratio as process hygiene criteria

The mean TVC on dressed porcine carcasses in abattoir A was 0.134% of the mean skin TVC on corresponding animals, whilst this value was 0.0069% in abattoir B (Table 4). In other words, abattoir B was roughly 19.4-fold more successful in reducing transfer of incoming, skin-borne TVC contamination onto the resulting carcasses. The mean EC on dressed porcine carcasses in abattoir A was 1.15% of the mean skin EC on corresponding animals, whilst this value was 0.23% in abattoir B (Table 4). In other words, abattoir B was 5-fold more successful in reducing transfer of incoming, skin-borne EC contamination onto the resulting carcasses. Therefore, both the TVC- and EC-relationship between carcass and skin microflora in corresponding pigs indicated that the process in abattoir B was markedly more hygienic, compared with abattoir A. This is in contrast to the fact that, as shown above, processes in the two abattoirs were either only marginally distinguishable (*via* TVC) or indistinguishable (*via* EC) when using the EU process hygiene criteria solely based on the mean values of dressed carcasses.

The *Salmonella* occurrence on dressed porcine carcasses in abattoir A was 50% of the occurrence on the skins of corresponding animals, whilst this value was 35% in abattoir B (Table 4). In other words, abattoir B was somewhat more successful in reducing transfer of incoming, skin-borne *Salmonella* contamination onto the resulting carcasses. Although this 15-percentile difference between *Salmonella* on skins and carcasses in abattoir B is not marked from practical perspective, it is in agreement with the findings based on both TVC- and EC-related carcass *versus* skin relationships also showing that abattoir B was significantly more hygienic than abattoir A (Table 4).

4. Discussion

The current microbiological EU process hygiene criteria (Regulation EC No 2073/2005, EC 1441/2007), applicable to abattoir operations, communicates the expected outcome of a process as end-manufacturing or end-product criteria. Considering the nature of end-product criteria, it is understandable that it has been indicated (Bolton et al., 2000; EFSA, 2007; Vivas Alegre & Buncic, 2004) that such PHCs define the expected final outcome of the processes, but they neither characterize nor differentiate between the processes themselves. This implies that current EU microbiological abattoir PHC need to be further improved if better hygienic characterisation and differentiation of the processes is desired.

The present study indicated that characterising each process and distinguishing between more or less hygienic processes in two commercial cattle and two pig abattoirs solely through their fitting into a acceptable, marginal or unacceptable category according to current EU PHC criteria based on TVC and EC levels on final carcasses was not sufficiently sensitive/effective. Namely, it is logical that in the case of two abattoirs that produced final carcasses having equal microbial levels, the abattoir that slaughtered animals with significantly higher pre-dressing (i.e. on skin) microbial levels actually had a better process hygiene performance than the other abattoir. In contrast, when the same abattoir processes were characterised through a parameter based on the ratio between TVC/EC levels on carcasses and on skins in corresponding animals, the effectiveness of the processes in reducing the transfers of incoming, skin-borne microflora onto dressed carcasses could be determined more precisely, and more or less hygienic processes could be distinguished more reliably. Overall, the present study, conducted under real life conditions, confirmed earlier findings obtained under experimental conditions using inoculated animals (Vivas Alegre & Buncic, 2004). Nevertheless, the potential advantages and usefulness of improved red meat abattoir PHCs based on TVC/EC carcass-skin ratios need to be further evaluated though more comprehensive studies involving a larger number of abattoirs with varying capacities and technologies.

In the present study, distinguishing between more or less hygienic processes solely through the occurrence of pathogens on final dressed carcasses (i.e. *Salmonella* in two pig abattoirs, *E. coli* O157 in two cattle abattoirs) also was not sufficiently sensitive/effective, because these occurrences of each pathogen did not differ meaningfully between processes and/or were in disagreement with corresponding TVC/EC trends. Similarly, occurrence-based *E. coli* O157 carcass–hide ratios also did not distinguish between the processes in cattle abattoirs, and occurrence-based *Salmonella* carcass-skin ratios differed only to a smaller extent between the processes in pig abattoirs. This is in accordance with the views of some other authors that, because pathogens occur on skins/carcasses relatively infrequently (compared with TVC and EC), in very low numbers and distributed unevenly, and also because they are affected not only by the processes' hygiene but also by the pre-abattoir chain of events, the use of pathogen-based microbiological criteria for abattoir process characterisation does not seem recommendable; instead, the use of indicator organisms is preferred (Bolton et al., 2000; Gill, Bryant, & Bedard, 1999; The role of microbiological testing, 1999). Rather, the main purpose of monitoring of pathogens on carcasses should be consumer exposure assessment and pathogen reduction programmes.

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