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Prerequisites of inspection conditions for uniform post-mortem inspection in broiler chicken slaughterhouses in Finland

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ABSTRACT

Meat inspection of broiler chickens (broiler) in the European Union is regulated by common legislation to secure meat safety. However, the legislation is general in nature and proper post-mortem inspection (PMI) of every carcass and visceral organs of broilers is challenging in slaughterhouses (SHs) with a high slaughter line speed. The aim of this study was to investigate the on-site organization and possible differences of the PMI in four Finnish SHs, which slaughter over 99% of broilers in Finland. Our results show that the meat inspector's available inspection time per broiler in the PMI varied between 0.28 and 0.90 s, with the shortest available inspection time in the SH with the highest slaughter line speed and the longest available inspection time in the SH with the slowest line speed. We observed that only part of the total inspection time per broiler could be used for true PMI in most (3/4) SHs, as the meat inspectors also performed other tasks during the PMI. We observed deficiencies in the visual inspection of broiler carcasses; in particular, the proper inspection of all or most of the body cavities was impossible in all SHs during the PMI. Some deficiencies in facilities (e.g. in recording system) were observed. Moreover, lighting properties varied between the SHs and a significant difference between illumination conditions at the first inspection stations in the SHs was observed. This study considered the prerequisites for proper PMI and revealed that the PMI of broilers was not completely uniform in Finland. The results emphasize the need for more precise guidelines and recommendations, especially for inspection time and lighting at inspection stations.

1. Introduction

The safety of broiler chicken (broiler) meat, produced in broiler slaughterhouses (SHs) and intended for human consumption, is secured by meat inspection. In the European Union (EU), meat inspection is regulated by EU legislation (EU 2017/625; EU 2019/624; EU 2019/627). The legislation aims to ensure that official inspections are performed in a uniform way. In the EU, over 10 million tonnes of broiler meat are produced and accepted as food per year (European Commission, 2020).

The meat inspection of broilers in SHs includes checks and evaluations of food-chain information of a flock and ante-mortem and post-mortem inspection (PMI) (EU 2017/625; EU 2019/627). In the PMI, the results from food-chain information analysis and ante-mortem inspection must be taken into account (EU 2019/627). According to the legislation, external surfaces of every carcass and their body cavities and visceral organs must be inspected. Broilers or parts of them that are declared unfit for human consumption must be rejected during PMI. The collected data on meat inspection can be used for evaluating broiler health and welfare (Huneau-Salaün et al., 2015; Stärk et al., 2014).

In broiler SHs, the arrangement of the PMI differs from meat inspection arrangements in the SHs of bovine animals and swine, where the slaughter line speed is slower, and the carcasses are split lengthways into half carcasses. The arrangement of the PMI differs because broiler production and broiler SHs have specific characteristics. The processes are highly automated in broiler SHs (Barbut, 2015; Marel Poultry, 2020). Thus, the slaughter line speed can be as high as 15 000 broilers per hour (Marel Poultry, 2020). The use of automated processes is possible because the slaughtered broilers are uniform in size. This is because broilers are raised according to similar production systems and have been bred exclusively for meat production (Aviagen, 2019; Zuidhof et al., 2014).

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The PMI of broilers is challenging because the total inspection time per broiler is short (EFSA, 2012; Löhren, 2012). Unlike bovine and swine SHs, the broiler SHs do not have a side lane where an official veterinarian can inspect carcasses later (Löhren, 2012). Meat inspectors must independently and rapidly make their decision to either accept or reject broilers or part of them. Therefore, the number and education of meat inspectors and the facilities at the inspection stations must be appropriate to ensure proper PMI according the legislation (MAF 795/2014; EU 2019/627; MAF 795/2014).

Broiler meat inspection is not performed in a harmonized way across the EU member states despite the common legislation of meat inspection (Löhren, 2012). Differences have been found in the number of meat inspectors per slaughter line, in the requirement of the minimum inspection time per broiler, and in the technical systems in use during the PMI (Löhren, 2012). One reason for this is the lack of precise requirements in the legislation, as Regulation (EU) 2019/627 only mentions that the speed of the slaughter line and the number of inspection personnel present shall be such as to allow for proper inspection. The requirements for the inspection time, the number of inspectors on the slaughter line, and facilities at the inspection stations are absent or are vague, such as the requirement for adequate lighting in the Codex Alimentarius Code of Hygienic Practice for Meat (2005). Accordingly, the lack of adequate requirements allows the diverse application of legislation and adversely affects the uniformity of meat inspection.

Adequate inspection of external surfaces of all broiler carcasses, body cavities, and visceral organs and performing all required measures (such as rejecting carcasses, washing hands, recording condemnations, and sterilizing knives) are challenging under the circumstances of broiler SHs. Therefore, proper practices and working conditions and educated personnel are necessary. However, practical organization of the PMI in the EU member states has been studied minimally, and basic knowledge on PMI conditions is inadequate.

The purpose of this study is to obtain information about the organization of the PMI in Finnish broiler SHs, identify differences between the SHs, and identify and describe possible deficiencies in the PMI.

2. Materials and methods

2.1. Slaughterhouses

The study included four broiler SHs (A–D) in Finland. In Finland, 79 million broilers were slaughtered in 2019 (FFA, 2020); these SHs slaughtered over 99% of them. The two largest SHs together slaughtered approximately 4.5 times as many broilers as two smaller ones combined. The broiler breed was Ross 308 and mean carcass weight after chilling was 1.4–1.8 kg, depending on the SH in 2019. Line speed was over 9000 broilers per hour in the two largest SHs and under 9000 broilers per hour in the two other SHs. Official veterinarians in the SHs were employees of the Finnish Food Authority (FFA), but the meat inspectors performing the activities of official auxiliaries were qualified staff of the SH that fulfilled the requirements set in the Regulation (EC) 854/2004, Annex I, Section III, Chapter III.

2.2. Investigation of the organization and working conditions of post-mortem inspection

The first author performed 2-day visits to each SH between September and October 2019. Permission was obtained from the SHs and the FFA before visits. During the visits, the organization and working conditions of the PMI were studied by observing the PMI practices, measuring the size of the PMI stations and the distances between meat inspectors and carcasses and visceral organs, and by collecting data on the facilities and equipment at every PMI station (Tables 1 and 2). The brightness of mirrors was estimated with a two-point scale (Table 2). The total inspection time for each broiler was calculated based on the slaughter line speed and the number of the meat inspectors at the PMI stations at the same time in the SH. The meat inspectors might also have had non-PMI tasks (i.e. tasks that were not a part of the PMI) during the PMI session at the PMI stations. These tasks were considered when the total true inspection time was calculated. The number of occasions that the meat inspector performed a non-PMI task during the PMI session was counted over 300 consecutive broilers during both visits to each SH. All the observations and measurements were done by the same researcher.

Table 1
Organization of the post-mortem inspection (PMI) in four Finnish broiler slaughterhouses (SHs) in autumn 2019.

Organization of PMI	First PMI station[a]	Second PMI station[b]
General information		
Number of SHs where the meat inspectors belong to qualified company staff of the SH working under the supervision of the official veterinarian	4 (100%)	4 (100%)
Mean number of meat inspectors at PMI stations in SHs where line speed < 9000 broilers/hour (range)	1.5 (1–2)	1.5 (1–2)
Mean number of meat inspectors at PMI stations in SHs where line speed > 9000 broilers/hour (range)	2.5 (2–3)	3.5 (3–4)
Number of SHs with possibility to make partial condemnations of carcasses	2 (50%)	2 (50%)
Number of SHs where meat inspectors also have tasks other than post-mortem inspection tasks during the PMI	3 (75%)	3 (75%)
Mean total true inspection time per one broiler (range) (seconds)[c]	0.7 (0.3–1.1)	0.8 (0.3–1.2)
PMI in practice		
Position of the carcass and/or visceral organs at the PMI station		
back towards a meat inspector	2 (50%)	
breast towards a meat inspector	2 (50%)	
back towards a meat inspector and visceral organs in front of the carcass		4 (100%)
Carcasses inspected from both sides (the other side in the mirror) at the SH	4 (100%)	4 (100%)
Visceral organs seen from both sides (the other side in the mirror) at the SH		3 (75%)
Possibility to inspect whole broiler at the first PMI station in the SH		
Yes	1 (25%)	
no (carcass without head and feet)	3 (75%)	
Inspection methods at the PMI station at the SH		
visual inspection of external surfaces (excluding body cavities)	4 (100%)	4 (100%)
palpation (and possibility to inspect some of body cavities at the second PMI station)	3 (75%)	3 (75%)
incision when necessary	3 (75%)	2 (50%)
Mean distance between meat inspector and carcass (range) (cm)	33 (30–37)	58 (45–74)
Mean distance between visceral organs and meat inspector (range) (cm)		44 (40–49)

[a] The point where the whole broiler is inspected after scalding and plucking.
[b] The point where the carcass and accompanying visceral organs are inspected after evisceration.
[c] Total true inspection time = the total inspection time for meat inspectors per broiler at the PMI stations without the time they performed tasks other than PMI tasks during the PMI.

The total true inspection time per one broiler (TI_{total}) during the PMI was calculated with the following formula:

$$\left[I - \frac{x_1 + y_1}{600} \times z\right] + \left[I - \frac{x_2 + y_2}{600} \times z\right] + \ldots + \left[I - \frac{x_n + y_n}{600} \times z\right] = TI_{total}$$

where I = a meat inspector's available inspection time per one broiler in PMI, which means the average inspection time that one meat inspector had per one broiler during the PMI. This was calculated by dividing 3600 s (1 h) by the maximum number of broilers transported on the slaughter line in 1 h. During this time, the meat inspector had to decide

Table 2
Working conditions during the post-mortem inspection (PMI) in four Finnish broiler slaughterhouses (SHs) in autumn 2019.

Working conditions at the PMI stations	First PMI station[a]	Second PMI station[b]
Size and equipment of the PMI stations		
Mirrors at the PMI stations		
mean length of mirrors in all (range) (cm)	278 (142–484)	305 (142–576)
condition of mirrors at the SHs		
good[c]	3 (75%)	3 (75%)
moderate[c]	1 (25%)	1 (25%)
Mean width of the PMI stations (range)(cm)	240 (84–360)	488 (245–920)
Mean width of the area for one meat inspector at the PMI stations (range)(cm)	136 (83–200)	195 (110–245)
Facilities to wash hands at the PMI stations in the SHs		
faucets with touchless function	3 (75%)	3 (75%)
faucets operated by knee	1 (25%)	1 (25%)
Facilities to sterilize knives at the PMI stations in the SHs		
sterilizers for knives	3 (75%)	2 (50%)
no need for sterilizers (knives were not used)	1 (25%)	2 (50%)
Recording of rejections at the PMI stations in the SHs		
touch screen/push button boards	3 (75%)	3 (75%)
form and pencil outside the PMI station	1 (25%)	1 (25%)
Other technical systems at the PMI stations in the SHs		
automatic rejecting system	1 (25%)	1 (25%)
line divider	0 (0%)	1 (25%)
height adjustment at the PMI station possible	3 (75%)	3 (75%)
Working in exceptional situations during PMI in the SHs		
alarm system at the PMI station for asking vet or technical help	3 (75%)	3 (75%)
meat inspectors have possibility to stop line	3 (75%)	4 (100%)
backup system for recording rejections if primary system is not functional	3 (75%)	3 (75%)

[a] The point where the whole broiler is inspected after scalding and plucking.
[b] The point where the whole carcass and accompanying visceral organs are inspected after evisceration.
[c] Good = bright reflective surface of a mirror; moderate = not perfectly bright reflective surface of a mirror.

whether to accept or totally or partially condemn the broiler and decide on the reason for condemnation.

x = the number of non-PMI tasks per meat inspector among 300 consecutive broilers during the PMI from the researcher's first visit to the SH. Subscript number (1, 2, …, n) describes the meat inspector's location at the PMI station.

y = the number of non-PMI tasks per meat inspector among 300 consecutive broilers during the PMI from the researcher's second visit to the SH. Subscript number (1, 2, …, n) describes the meat inspector's location at the PMI station.

z = estimated time needed to complete one non-PMI task. This time was determined by timing the duration of 100 non-PMI tasks in one of the SHs and dividing that time by 100. The purpose was to get an approximate time for one non-PMI task, as the tasks varied during the PMI in the SHs.

To collect information about the arrangements during exceptional situations (e.g. during a slaughter process disruption), the PMI personnel were interviewed about their procedures in performing emergency or compensatory measures (Table 2, Suppl. Data). All data from studies were collected on a pre-structured form.

2.3. Investigation of lighting at the post-mortem inspection stations

During the visits, the researcher measured lighting at the PMI stations with the spectral light meter MSC15 (Gigahertz Optik GmbH). Illuminance, colour rendering index, and colour temperature were measured from both the front side and backside of the carcass at the first PMI station and from the front side of the liver at the second PMI station. The colour rendering index describes to what degree the investigated light reproduces the colours of the object illuminated by this light compared with the colour rendering of the reference light (CIE, 17-22-109). Colour temperature (expressed in Kelvin) describes the colour appearance of the light (CIE, 17-23-067).

The colour rendering index, colour temperature, and illuminance were measured with the light meter in a horizontal plane next to the examined carcass at the breast level. Additionally, the illuminance was measured with the light meter that was parallel to the examined surfaces of a liver and a carcass (neck, breast, abdomen, thigh, hock, and back) to measure real lighting conditions on the carcass and liver when they were hanging on the slaughter line. Each measurement was repeated, and the result was the mean of these two measurements.

2.4. Collecting data of the meat inspection personnel

The chief official veterinarian of each SH that participated in the study was interviewed to gather information about the meat inspection personnel. The number of, education, and work history of the meat inspectors and the number of and work history of the official veterinarians in the SHs were requested (Suppl. Data). The number of permanent personnel per million broilers was counted by dividing the entire number of personnel by the number (in millions) of broilers brought to slaughterhouse in 2019 (Table 3). The number of broilers brought to the SHs were asked from the FFA.

2.5. Statistical analysis

Data processing and creation of figures were performed in Excel® for Office 365 (Microsoft Corp., Redmond, WA, USA). Statistical analyses were performed using SPSS® Statistics Version 25 (IBM Corp., New York, USA). The significance of the differences between the illuminances of the SHs at the first inspection station were analysed with Kruskal-Wallis Test and pairwise comparisons with Bonferroni correction. Non-parametric tests were used because the data were not normally distributed in all SHs. The Shapiro-Wilk test was used to test normality. The ϵ^2 estimate was calculated as an effect size estimate after the Kruskal-Wallis Test. P-values < 0.05 were considered as statistically significant.

Table 3
Summary data of the personnel in the post-mortem inspection in four Finnish broiler slaughterhouses (SHs) in autumn 2019.

Variable	Meat inspectors[a]	Official veterinarians
Mean number of permanent personnel per million broilers in SHs with slaughter line speed		
<9000 broilers/hour (meat inspectors, n = 17; official veterinarians, n = 3.2)	1.2	0.2
> 9000 broilers/hour (meat inspectors, n = 59; official veterinarians, n = 6)	0.9	0.1
Work experience of permanent personnel		
1 year	0	0
1–5 years	29 (38%)	5 (50%)
> 5–10 year	12 (16%)	0
> 10 years	35 (46%)	5 (50%)
Training requirements are fulfilled to the satisfaction of the competent authorities	76 (100%)	10 (100%)

[a] Qualified slaughterhouse staff, who performed the activities of the official auxiliaries and who fulfilled the regulations set in Regulation 854/2004, Annex I, Section III, Chapter III.

3. Results

3.1. General information of the post-mortem inspection in the slaughterhouses

All SHs in this study had the first PMI station after scalding and plucking and the second PMI station after evisceration. The number of meat inspectors at the PMI stations differed; the mean number of the meat inspectors was six in the two SHs with faster slaughter line speed (>9000 broilers/hour), which was twice as much as in the SHs with slower slaughter line speed (<9000 broilers/hour) (Table 1). Although the entire number of meat inspectors was the same among the SHs with slower slaughter line speed, the division of meat inspectors between the PMI stations differed (Table 1). The same was observed among the SHs with faster slaughter line speed.

The meat inspector's available inspection time per one broiler in PMI differed between the SHs. The shortest available inspection time was 0.28 s in the SH with the fastest slaughter line speed, while the longest available inspection time was 0.90 s per broiler in the SH with the lowest slaughter line speed.

The mean total inspection time was 2.1 s (variation between SHs was 1.7–2.7 s) per broiler during the PMI but the mean total true inspection time was 1.6 s (variation between SHs was 1.4–1.7 s) per broiler (Fig. 1). The difference between the mean total inspection time and mean total true inspection time per broiler was due to the non-PMI tasks that the meat inspectors performed during the PMI in three out of four SHs. The non-PMI tasks differed between SHs. The non-PMI tasks included the manual evisceration of a carcass in case whole or a part of visceral organs were inside the carcass, the cutting off heads, re-shackling of dropped carcasses, or putting the leg back in the shackle and removing tail or other feathers from carcasses.

In addition to condemnation of whole carcasses, partial condemnations were also performed in three SHs (Table 1). In one SH, partial condemnation was impossible due to the high slaughter line speed and the physical space between the meat inspector and carcass at the second PMI station. The condemned parts and causes for condemnations varied between three SHs. Wings could be condemned in three SHs, breast skin in two SHs, and the posterior part of carcasses with faecal contamination in one SH. Furthermore, legs with mild infections or bruises in one SH and a part of wings with bruises in the other SH were marked for trimming later in the cutting plant.

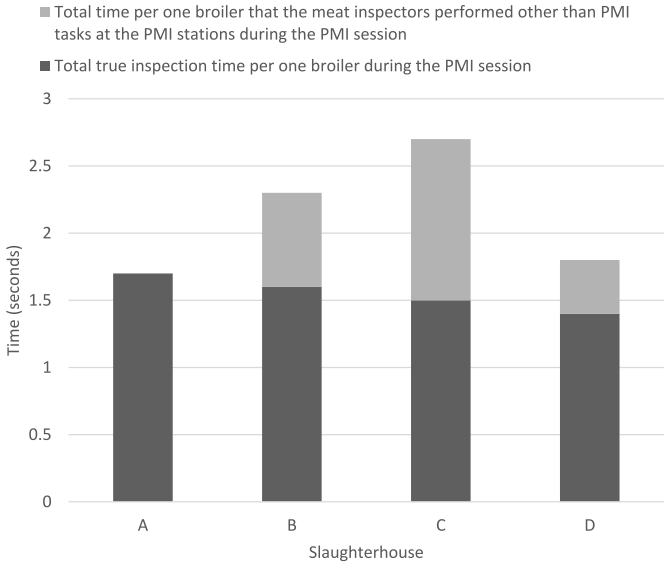

Fig. 1. Total time per one broiler for meat inspectors who were at the post-mortem inspection (PMI) stations at the same time during the post-mortem inspection (i.e. total inspection time at the Finnish broiler slaughterhouses).

3.2. Post-mortem inspection practices

The inspection method at all PMI stations was visual inspection of external surfaces (Table 1). An entire broiler was impossible to inspect in three SHs because heads and feet were removed before the first PMI station. During the PMI, the proper inspection of body cavities was impossible in one SH. In three SHs, the inspection of body cavities (by tilting the carcass) was possible only for a few body cavities when soiling or viscera package or its remnants were suspected inside body cavities.

Palpation and incisions were possible in three SHs (Table 1). However, in one of those SHs, possible palpation or incision could be performed only on the carcass' back side, as the front side was inspected only by the mirror (Table 1).

3.3. Size and equipment of post-mortem inspection stations

Every PMI station was equipped with a mirror for inspecting the opposite side of the carcasses and visceral organs (Table 2). Most of the mirrors were in good condition. However, the view in the mirrors was considered moderate at both inspection stations in one SH because the mirrors' reflective surfaces were not perfectly bright. In one SH, only the neck and breast of broilers were properly seen in the mirror at the first PMI station because of the position of the mirror. In another SH, the other side of visceral organs was not visible in the mirror at the second PMI station due to mirror positioning.

The width of the PMI station depended on the number of meat inspectors at the station. The second PMI station was always wider than the first PMI station. The mean width of space for one meat inspector was 136 cm at the first PMI station and 195 cm at the second PMI station (Table 2). Automatic height adjustment of the work platform was possible at three PMI stations and height adjustment via a transferable platform or height-adjustable seats were also used at three PMI stations. In one SH, it was not possible to change the working height at the PMI stations. Equipment to wash hands were at every PMI station next to the meat inspectors (Table 2). When necessary, knives could be sterilised at the PMI stations in all three SHs where meat inspectors had knives and made incisions.

Three SHs had touch screens or push-button boards next to the meat inspectors for recording rejections. However, in one SH, the meat inspector had to turn and walk 2.0 m away from the first PMI station and 1.2 m away from the second PMI station to record the rejections on the form (Table 2). An automatic rejection system was in use in one SH, while rejections were performed manually in the other SHs.

An alarm system for requesting technical assistance or help from the official veterinarian was absent in one SH. The alarm could be sounded by using an alarm bell or by calling in three SHs.

3.4. Meat inspection personnel

The mean number of meat inspectors per million broilers was lower in the SHs with a slaughter line speed >9000 broilers/hour than in the SHs with a slaughter line speed <9000 broilers/hour (Table 3). However, the lowest number (0.5 meat inspectors per million broilers) was in the SH with a slaughter line speed < 9000 broilers/hour. In that SH, the number of meat inspectors was over three times lower than the number in the other SH in the same group (1.9 meat inspectors per million broilers). In one SH in the other group, the number of meat inspectors was also low (0.7 meat inspectors per million broilers), as the other workers assisted meat inspectors by performing tasks where education for the PMI was not required.

The mean number of the official veterinarians per million broilers was twice as much in the SHs with a slaughter line speed <9000 broilers/hour as in the SHs with a slaughter line speed >9000 broilers/hour (Table 3).

The meat inspection staff was qualified and experienced (Table 3).

3.5. Lighting at the post-mortem inspection stations

Our results reveal variation in the illuminance, colour rendering index, and colour temperature between the PMI stations and the SHs. In two SHs, the colour rendering index varied between the first (88 and 80) and second PMI station (75 and 95) (Table 4). In the two other SHs, the colour rendering index was between 80 and 85. The maximum colour temperature was 4812 K and minimum 3560 K (Table 4). Kruskal-Wallis test showed that the illuminance on the surface of the carcass at the first PMI station varied significantly between the SHs ($P < 0.01$, $\epsilon^2 = 0.745$). A post-hoc test using pairwise comparisons with Bonferroni correction showed significant differences in slaughterhouse pairs AB ($P < 0.01$) and AC ($P = 0.042$) (Fig. 2). While the best illuminance at the second PMI station was in SH B, the poorest illuminance of all was at the first PMI station in the same SH. The poorest illuminance value at the second PMI station was in SH D (Fig. 2.).

4. Discussion

The basic prerequisite for the organization of the PMI according to the requirements of Commission Implementing Regulation (EU) 2019/627 and before that of Regulation (EC) 854/2004 is that all external surfaces of broiler carcasses and accompanying visceral organs can be inspected to find visible diseases, defects, or contamination. To fulfil the requirements of the legislation, sufficient inspection time, suitable inspection methods, proper facilities, equipment, and lighting at the PMI stations, and a sufficient number of educated meat inspection personnel are needed for the organization of the PMI. However, our study showed that this organization was not uniformly executed in large Finnish broiler SHs. For example, we observed differences in the total inspection time, the inspection methods, and the lighting at the inspection stations. These differences impaired the uniformity of the PMI. The current study was conducted before the application of Commission Implementing Regulation (EU) 2019/627, in which the principles are quite similar as in the Regulation (EC) 854/2004 ([EC] 854/2004 was applied during this study).

We observed that the total inspection time that the meat inspectors at the PMI stations had per one broiler together was only partially used for PMI tasks in three out of four SHs. The time that meat inspectors performed non-PMI tasks was almost half of the total inspection time in one SH. This emphasizes the importance of securing a total true inspection time of sufficient length that the meat inspectors must have for PMI tasks. Regulation (EU) 2019/627, and the previous Regulation (EC) 854/2004, do not set requirements for the total inspection time. The national requirement for the minimum inspection time per bird was 3 s in Austria and 2.5 s for poultry up to 1.5 kg in Germany (Löhren, 2012).

Table 4
Colour temperature and colour rendering properties of lighting at the post-mortem inspection (PMI) stations in four Finnish broiler slaughterhouses (N = 4) in autumn 2019.

Properties	First PMI station[a]		Second PMI station[b]	
	N	%	N	%
Colour temperature				
3500 K to <4000 K	1	25	0	0
4000 K to <4500 K	3	75	3	75
4500 K to <5000 K	0	0	1	25
Colour rendering index				
75 to <80	0	0	1	25
80 to <85	2	50	2	50
85 to <90	2	50	0	0
90 to ≤95	0	0	1	25

[a] A point where the PMI of the whole broiler is performed after scalding and plucking.

[b] A point where the PMI of carcasses and accompanying visceral organs of broilers is performed after evisceration.

It remains uncertain if the meat inspectors' non-PMI tasks have been considered in these inspection times. However, our study revealed that each Finnish SH had a longer total true inspection time than the estimated total inspection time in Germany and in the United Kingdom (1 s) (Löhren, 2012). When interpreting the results of the total true inspection time in the Finnish SHs, it should be noted that the number of non-PMI tasks varied, and the results are based on the situation during the researcher's two visits to each SH. Thus, the total true inspection times are approximate.

The meat inspector's available inspection time per one broiler in the PMI was only 0.28 s in the SH with the highest slaughter line speed. This amount of time is only one third of the longest available inspection time that one meat inspector had for one broiler in the other SH with the slowest slaughter line speed. However, studies on the minimum inspection time that one meat inspector needs to perform adequate PMI are lacking. Earlier studies have shown that the simple reaction time, which means only a simple reaction to one kind of visual signal, is approximately 0.2 s. However, the intensity of the signal affects this time (Luce, 1991). When a person must choose how to react to different signals, the required reaction time increases (Luce, 1991; Weldorf, 1971). For example, the reaction time depends on how easy it is to perceive the signal and the right response (Weldorf, 1971). During the PMI, the meat inspectors must detect various defects in the carcasses, decide whether to condemn or accept the carcass, and, if necessary, reject it and record condemnation reason. Although the reaction time can be shortened by simplifying the tasks that each meat inspector must perform, the shortest available inspection time observed for one carcass in the present study seemed to be very short. The requirement of at least 0.4 s per carcass (no more than 140 birds per minute) in the New Poultry Inspection System in the United States support this observation (USDA, 2019a; Mendonça). However, the slaughtering speed may be even 15 000 broilers per hour in modern SHs (Marel Poultry, 2020). This means that a meat inspector has an inspection time of 0.24 s per a broiler. The meat inspector's short available inspection time for PMI per one broiler at a high slaughter line speed is one reason that supports the development of new automatic inspection systems for the inspection of broiler carcasses and visceral organs (Chao et al., 2010; Jørgensen et al., 2018).

Based on an earlier discussion, companies and competent authorities must remember that there is a threshold for available inspection time that a meat inspector needs to correctly perform the PMI. These findings indicate that further investigations for determining the meat inspector's available inspection time per one broiler in PMI are warranted in the future.

Our results indicate that to some extent the PMI was performed in different ways in the SHs. In one SH, incision, palpation, and partial condemnations were not conducted besides the visual inspection. In three SHs, the head and feet were removed before the PMI. Removing feet before the PMI makes it difficult to discover arthritis in a hock, which is often caused by *Staphylococcus aureus* and *Escherichia coli* (Butterworth, 1999). These bacteria also contaminate cutting equipment and can thus spread to other carcasses. Palpation and incision of the carcass and visceral organs are allowed when necessary (EC No 854/2004;EU 2019/627). For instance, these methods may be needed when cellulitis is suspected in a carcass. Cellulitis is an inflammation under the skin and may be very difficult to detect (Norton R.A. et al., 1997; Vaillancourt & Barnes, 2008). In the study of St-Hilaire and Sears (2003) in Ontario, the type of inspection systems was confirmed to be one factor in the variation of condemnation rates due to cellulitis between SHs. However, any handling of carcasses increases the risk of carcass contamination, although washing hands and sterilizing knives properly afterwards decreases the bacterial load (Rahkio & Korkeala, 1996; Durmuşoğlu et al., 2020). In this study, the inspection methods were affected by the area of the carcass facing the meat inspector, as incisions on the breast side are not possible if the back of the carcass is towards the meat inspector. In addition, palpation and incision cannot be performed if the carcass is far from the meat inspector, which was the case in one SH in this study. In the SHs where the other side of the carcass can be only inspected in the mirror, suitable positioning, condition, and brightness

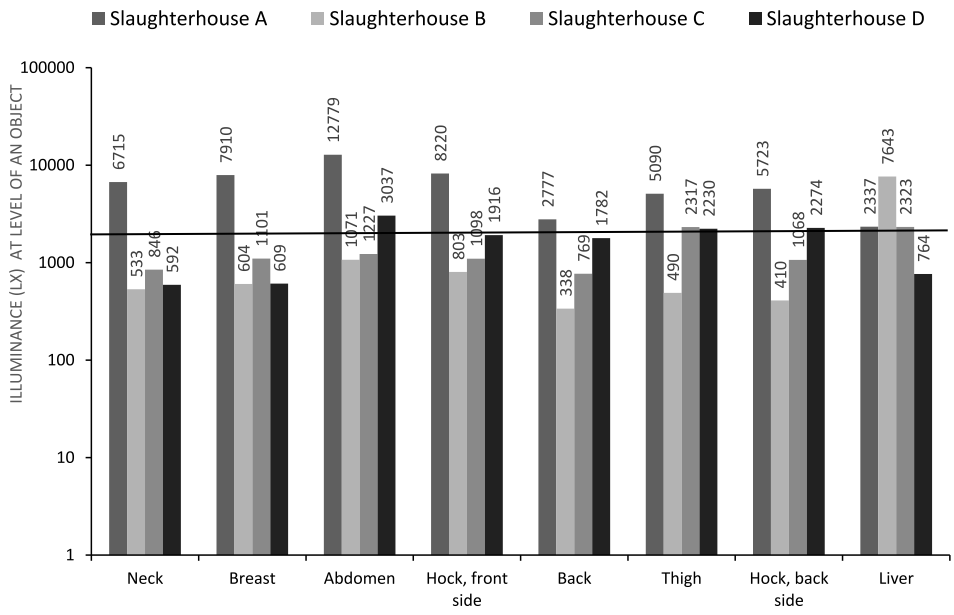

Fig. 2. Illuminance on different areas of a carcass and illuminance of a liver at the post-mortem inspection stations in four Finnish broiler slaughterhouses. The measurement was performed in such a way that the meter was parallel to the examined area of the carcass or the liver. The black line shows the level of 2000 lx, which is the illuminance requirement in the USA (200 footcandles, or approximately 2153 lx) and Canada (at the carcass abdominal cavity level) (CFIA, 2019; USDA, 2019b).

of the reflective surface of the mirror is especially important. If increased uniformity of PMI is sought, inspection methods should be harmonized.

The proper inspection of the body cavities of all carcasses was not possible during the PMI due to the high slaughter line speed and the insufficient number of the meat inspectors in the SHs. The inspection of body cavities takes time and is usually impossible to perform properly without touching and tilting the carcass. In three SHs, a few body cavities, mainly those with a suspicion of faecal contamination or failed viscera removal process, were possible to inspect within the PMI. In addition to quality problems, a failed viscera removal process increases the risk of faecal contamination (Hue et al., 2010; Rasschaert et al., 2020), which consequently increases the risk of food pathogens on carcasses, especially in body cavities. In particular, an automated evisceration process increases the risk of ruptured intestine and thus the risk of faecal contamination (Hue et al., 2011). Although the inspection of body cavities of carcasses is very important, fulfilling the requirement in Regulation (EU) 2019/627 to view the body cavities of all carcasses is difficult to perform properly if the slaughter line speed is high. At the time of our study, Regulation (EC) 854/2004 was applied and the requirement to also view external surfaces of body cavities was not specifically mentioned in that regulation. We cannot compare the number of meat inspectors in SHs between Finland and other EU countries, as most of the EU countries did not provide information about the number of meat inspectors at the PMI stations, as in Löhren's report (2012). However, we can presume that other EU countries that have SHs with a high slaughter line speed also experience the same challenge in inspecting body cavities during the PMI.

Few deficiencies in the facilities were seen at the inspection stations. The inspection conditions were impaired because the recording system was far from the slaughter line and the height adjustment of the inspection station was not possible. These deficiencies affected the performance of the PMI, because at high slaughter line speed, the meat inspectors must be able to concentrate on the PMI and they must have the possibility to inspect the external surfaces of the carcasses and the body cavities without difficulties. Some of these deficiencies, such as height adjustment of the inspection station, should have been noticed already when the SH was approved by the authorities, although the EU legislation lacks precise requirements of the facilities at the inspection stations.

Each SH in the study adequately fulfilled the requirements in Regulation (EC) 853/2004 concerning equipment, such as hand washing and sterilizing knives at the inspection stations. Furthermore, accessibility of the equipment was appropriate as they were situated close to the meat inspectors. This is important, as good accessibility of the disinfection equipment increases sterilization of knives (Rahkio & Korkeala, 1996).

The differences detected between the SHs in the lighting properties of the PMI stations (illuminances, colour rendering indexes, and colour temperatures) clearly affect how well meat inspectors can see carcasses and visceral organs and notice discolorations. Detecting of colour differences is important in the successful identification of tissue for condemnation (Collins & Worthey, 1984). In addition to the illuminance level, the colour characteristics (colour rendering index and colour temperature) of the light source influence the condemnations in PMI. Unfortunately, there is minimal research on what is adequate lighting in PMI and the EU legislation does not provide guidance. In the USA and Canada, the illuminance requirements are 200-footcandles (approximately 2153 lx) and 2000 lx (at the carcass abdominal cavity level), respectively, and 85 for the minimum value of the colour rendering index (R_a) (USDA, 2019b; CFIA, 2019). The recommendations in the European Standard (EN 12464–1:2011) for colour inspection in the food industry are 1000 lx for illuminance and 90 for colour rendering index. The recommendation for a colour temperature is 4000–5000 K (CSIRO Food and Nutritional Sciences, 1997). According to our study, the illuminance, measured such that the light meter was parallel to the examined areas of the carcass or the liver, was over 2000 lx at each inspection station only in one SH. In the other SHs, the illuminance on the examined areas of the carcass was many times under 1000 lx. The illuminance also varied between different areas of carcasses, indicating that more attention should be paid to equally illuminating all areas of carcasses. In addition, less than half of the inspection stations had lighting with a colour rendering index of 85 or greater, while the colour temperature was 4000 K or over in almost all (7/8) PMI stations. As the meat inspectors examine the carcasses and the visceral organs hanging on the slaughter line, it is important to measure the illuminance with a light meter that is parallel to the examined surfaces of a carcass and visceral organs. This is also how the limit values were determined in the European Standard EN 12464–1:2011. However, the lighting requirements in the USA and Canada do not indicate the plane in which the illuminance should be measured, thus the limit value of 2000 lx could also be

measured at the horizontal level. In this case, the results of our study would be better because the illuminance measured at horizontal level was under 2000 lx only at two PMI stations out of eight. In addition, the colour rendering index inadequately describes the visual perception of colour rendering of white LED lights (CIE 177:2007 177:2007). Thus, LED lights at five PMI stations out of eight in the participating SHs complicates the comparison even further.

Our results show that PMI conditions can be compared using the measurements of e.g. lighting and inspection time, and that these measurements can be used in SH audits. For this purpose, validated methodology should be developed in the future.

5. Conclusion

In conclusion, the high slaughter line speed of broiler SHs creates challenges in providing an appropriate available inspection time for a meat inspector per one broiler in the PMI, particularly for inspecting body cavities. Furthermore, differences in the number of meat inspectors at the PMI stations and the total inspection time per one broiler, lighting, and inspection methods may affect the PMI outcome. The recognized differences in the PMI of broilers within one country suggest that similar problems are also present in other countries. These results emphasize the need for more precise guidelines to ensure uniform PMI among EU countries and support further studies to understand how well the current PMI fulfils the demands of the EU legislation on controlling slaughter hygiene, securing meat quality, and monitoring broilers' health and welfare.

Declaration of interest

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CRediT authorship contribution statement

K. Törmä: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Visualization. **J. Lundén:** Writing – review & editing. **E. Kaukonen:** Writing – review & editing. **M. Fredriksson-Ahomaa:** Writing – review & editing, Supervision. **R. Laukkanen-Ninios:** Conceptualization, Resources, Writing – review & editing, Visualization, Supervision.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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