Livestock Science 193 (2016) 78–87

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Application of the Welfare Quality® protocol in pig slaughterhouses of five countries

Antoni Dalmau[a,*], Alexandre Nande[b], Madalena Vieira-Pinto[b], Silvia Zamprogna[c], Guido Di Martino[c], Juliana C.R. Ribas[d], Mateus Paranhos da Costa[d], Katri Halinen-Elemo[e], Antonio Velarde[a]

[a] IRTA, Veïnat de Sies s/n, Monells, 17121 Girona, Spain
[b] Veterinary School, CECAV – Universidade de Tras-os-Montes e Alto Douro, Quinta de Prados, 5001-801 Vila Real, Portugal
[c] Istituto Zooprofilattico Sperimentale delle Venezie, Viale dell'Università 10, 35020 Legnaro, Padova, Italy
[d] Department of Animal Science, FCAV-UNESP, 14884-900 Jaboticabal, SP, Brazil
[e] Animal Health ETT ra, Animal Welfare, Huhtalantie 2, 60100 Seinäjoki, Finland

ARTICLE INFO

Keywords:
Animal welfare
Assessment protocol
Behaviour
Human-animal relationship
Pigs
Sus scrofa

ABSTRACT

The objective of the present study is to assess the variability of the measures used in the welfare quality (WQ) protocol for pigs among slaughterhouses in five different countries and to propose alarm and critical thresholds for the calculation of scores for future development of an animal welfare certification scheme. The WQ protocol was applied in 52,468 pigs in 42 slaughterhouses in 5 countries (Portugal, Italy, Finland, Brazil and Spain). The welfare assessment started in the unloading area, where measures of general fear, thermoregulation, slipping and falling, lameness, sickness and mortality were taken. Concerning lairage, space allowance, drinking points, thermoregulation and mortality were considered, and the human-animal relationship was assessed by means of high-pitched vocalisations when pigs were moved from lairage to the stunning system. Finally, stunning effectiveness, skin lesions and presence of pneumonia, pleurisy, pericarditis and white spots on the liver were assessed in the stunning area and after slaughtering the animals. There was a large degree of variability among slaughterhouses for measurements made. For instance, the percentage of animals slipping ranged from 0.4% to 57%. Pigs with signs of recovery after stunning ranged from 0% to 90% and the percentage of carcasses that were severely damaged with skin lesions ranged from 0% to 48%. The data obtained can be useful to establish some thresholds for future uses of the WQ protocol. Electric stunning was associated with more animals recovering consciousness than from CO_2.

1. Introduction

EU citizens regard the welfare status of farm animals as an important aspect of overall food quality (Eurobarometer, 2016). Welfare Quality® (WQ) was an EU-funded project designed to integrate farm-animal welfare into the food-chain to address societal expectations and market demands by developing reliable on-farm and slaughterhouse welfare assessment systems. After discussions with consumers, representatives of key stakeholder groups, policy-makers and scientists, Welfare Quality® defined four animal welfare principles: 1) Good feeding, 2) good housing, 3) good health and 4) appropriate behaviour. Within these principles, the project highlighted distinct but complementary animal welfare criteria (Botreau et al., 2007). For each one of these criteria, different measures were developed for on-farm as well as slaughterhouse application (Dalmau et al., 2009a; Welfare Quality, 2009). Several areas are considered in this monitoring system to assess pig welfare at the slaughterhouse, such as the unloading, from unloading to lairage, lairage, from lairage to stunning, the stunning area and after slaughter (Table 1). The measures of the Welfare Quality® protocols can be aggregated to obtain an overall assessment of the welfare conditions in a slaughterhouse and on the farm. Furthermore, welfare can also be assessed within the specific areas within a slaughterhouse to identify possible risk factors or specific problems, such as heat or cold stress on arrival. However, in contrast to other WQ protocols, such as for pigs on the farm (Botreau et al., 2013), the aggregation scoring for assessment at slaughterhouse was not developed during the WQ project (Welfare Quality, 2009). One of the main problems when an aggregation scoring must be performed is to define what is acceptable or not or to establish what the alarm (something is wrong and an action is recommended) and critical (an

* Corresponding author.
E-mail address: antoni.dalmau@irta.es (A. Dalmau).

http://dx.doi.org/10.1016/j.livsci.2016.10.001
Received 30 May 2016; Received in revised form 30 September 2016; Accepted 1 October 2016

Table 1
Principles, criteria and measures of the Welfare Quality protocol for pigs at the slaughterhouse with indication of the place within the plant where the assessment is carried out and the sampling used.

	Welfare criteria	Measures	Place	Sampling per slaughterhouse
Good feeding	Absence of prolonged thirst	Water supply (number of drinking points per pig)	Lairage	Animals from 8 pens
Good housing	Comfort around resting	Density and flooring of lorries	Unloading area	Animals from 6 lorries
		Density in pens	Lairage	Animals from 8 pens
	Thermal comfort	Percentage of animals shivering or panting	Unloading area	Animals from 6 lorries
		Percentage of animals shivering, panting or huddling	Lairage	Animals from 8 pens
	Ease of movement	Percentage of animals that slip and/or fall	Unloading area	Animals from 2 lorries
Good health	Absence of injuries	Skin lesions	After killing	60 carcasses
		Lameness score	From unloading area to lairage	Animals from 2 lorries
	Absence of disease	Percentage of sick animals on arrival and dead animals on arrival	Unloading area	Animals from 6 lorries
		Percentage of dead animals	Lairage	Animals from 8 pens
		Slaughter checks (pneumonia, pleurisy, pericarditis, white spots in the liver)	After killing	60 animals
	Absence of pain induced by management procedures	Stunning effectiveness (presence of corneal reflex, righting reflex, rhythmic breathing, vocalisations)	Stunning area	60 animals
Appropriate behaviour	Good human-animal relationship	High pitched vocalisations	From lairage to stun	12 min (3 periods×4 min)
	Absence of general fear	Reluctance to move and turning back	Unloading area	Animals from 2 lorries

Table 2
Pigs slaughtered per day (Pigs/day), season (Time), stunning system used (Stun), approximate body weight of the animals slaughtered (Body weight) and pigs assessed in the unloading area (between brackets, the number of trucks assessed), lairage (in brackets, the number of pens assessed), in the stunning area (Stun), carcasses after killing the animals (Carcass) and lungs, hearts and livers (Viscera) per slaughterhouse.

Slaughterhouse	Pigs/day	Time*	Stun*	Body weight	Pigs assessed				
					Unloading (trucks)	Lairage (pens)	Stun	Carcass	Viscera
Portugal-1	360	AUT	GAS	110	1252 (6)	282 (8)	60	60	60
Portugal-2	320	AUT	ELEC	110	258 (3)	290 (8)	60	60	60
Portugal-3	1600	AUT	ELEC	110	411 (3)	367 (8)	60	60	60
Portugal-4	1200	AUT	ELEC	110	580 (3)	236 (8)	60	60	60
Portugal-5	1600	AUT	GAS	110	807 (6)	145 (8)	60	60	60
Portugal-6	1200	AUT	ELEC	110	986 (6)	263 (8)	60	60	60
Portugal-7	1300	AUT	GAS	110	571 (3)	275 (8)	60	60	60
Portugal-8	1300	AUT	GAS	110	482 (3)	247 (8)	60	60	60
Italy-1	1200	SUM	ELEC	160	836 (7)	92 (8)	60	60	60
Italy-2	1200	SUM	ELEC	160	802 (6)	224 (8)	60	60	60
Italy-3	3500	SUM	ELEC	160	818 /7)	109 (8)	60	60	60
Italy-4	2200	SUM	ELEC	160	855 (7)	163 (8)	60	60	60
Italy-5	1800	SUM	GAS	160	770 (7)	176 (8)	60	60	60
Italy-6	3600	AUT	GAS	160	787 (7)	161 (8)	60	60	60
Italy-7	3200	AUT	ELEC	160	796 (6)	169 (8)	60	60	60
Italy-8	2200	AUT	ELEC	160	784 (6)	178 (8)	60	60	60
Italy-9	700	AUT	ELEC	160	804 (6)	64 (8)	60	60	60
Finland-1	3000	SUM	GAS	110	1068 (8)	112 (8)	60	60	60
Finland-2	600	SUM	GAS	110	662 (12)	126 (8)	60	60	60
Finland-3	1300	SUM	GAS	110	1000 (6)	118 (8)	60	60	60
Finland-4	300	SUM	GAS	110	932 (6)	105 (8)	60	60	60
Finland-5	2800	SUM	GAS	110	1176 (7)	129 (8)	60	60	60
Brazil-1	1400	SUM	ELEC	110	618 (6)	753 (8)	60	60	60
Brazil-2	2500	SUM	ELEC	110	615 (6)	480 (8)	60	60	60
Brazil-3	1800	SUM	ELEC	110	584 (6)	641 (8)	60	60	60
Brazil-4	2000	SUM	ELEC	110	615 (6)	592 (8)	60	60	60
Brazil-5	400	SUM	ELEC	110	335 (6)	188 (8)	60	60	60
Brazil-6	800	WIN	ELEC	110	656 (6)	420 (8)	60	60	60
Brazil-7	300	WIN	ELEC	110	265 (6)	58 (5)	60	60	60
Brazil-8	9600	WIN	ELEC	110	528 (6)	680 (8)	60	60	60
Brazil-9	1500	WIN	ELEC	110	622 (6)	398 (8)	60	60	60
Brazil-10	1400	WIN	ELEC	110	612 (6)	272 (8)	60	60	60
Spain-1	6400	SPR	GAS	110	1335 (6)	368 (8)	60	60	60
Spain-2	3500	SPR	GAS	110	713 (6)	262 (8)	60	60	60
Spain-3	6200	SPR	GAS	110	1302 (6)	261 (8)	60	60	60
Spain-4	6000	SPR	GAS	110	1210 (6)	175 (8)	60	60	60
Spain-5	4300	SPR	GAS	110	1037 (6)	212 (8)	60	60	60
Spain-6	4500	SUM	GAS	110	864 (6)	167 (7)	60	60	60
Spain-7	2600	SUM	ELEC	110	794 (6)	390 (8)	60	60	60
Spain-8	4800	SUM	GAS	110	1265 (6)	1030(8)	60	60	60
Spain-9	4000	SUM	ELEC	110	1055 (6)	263 (8)	60	60	60
Spain-10	900	SUM	GAS	110	440 (6)	365 (8)	60	60	60

* AUT: Autumn; SUM: Summer; WIN: Winter; SPR: Spring. GAS: CO2; ELEC: Electric system.

action is obligatory) thresholds to be applied are. In the Welfare Quality project, for instance, for pig protocol at the farm, expert opinions were used to calculate these thresholds (Botreau et al., 2013). However, due to the lack of previous works in the assessment of pig welfare at the slaughterhouse, especially by using animal-based measures, it was very difficult to use the same methodology. In consequence, at the moment, an aggregation scoring for the measures assessed in the WQ protocol for pigs at the slaughterhouse does not exist. The general purpose of the present work is, then, to provide experts with the outcomes of different slaughterhouses assessed with a common protocol, the WQ protocol, as a basis for discussion on thresholds for certification schemes on pig welfare at the slaughterhouse. These certification schemes can then be used to improve animal welfare by defining what the acceptable and unacceptable levels are for a measure or group of measures. To carry out this general objective of the study, during the last few years, assessors of five countries have applied the WQ protocol for pigs in slaughterhouses, after attending a standardised training course developed within the Welfare Quality® project. By studying the variability of the measures in different slaughterhouses, it is possible to ascertain the capacity of improvement on animal welfare and to establish reasonable thresholds for certification schemes. For instance, if Slaughterhouse A has 20% of animals affected by Parameter X for years, the manager can defend that this is impossible to be reduced. Nevertheless, if when compared with other slaughterhouses there are some where the percentage is 2%, it means that 20% can actually be reduced. On the other hand, if the minimum value found is 2%, even in the best slaughterhouse, this must be taken into account when thresholds are defined. If we define a threshold of acceptance for this parameter as being of 0%, the capacity of discriminating between good and bad slaughterhouses of the tool disappear, as both slaughterhouses (one with 2% and one with 20%) will have the same score. In this context, the certification scheme is not useful to improve animal welfare. The objective of the present study is then to assess the variability of the WQ outcomes among slaughterhouses. In addition, alarm and critical thresholds are proposed for the calculation of scores in the scope of the future development of certification schemes to assess pig welfare at the slaughterhouses.

2. Materials and methods

The WQ protocol was applied in 8 Portuguese, 9 Italian and 5 Finnish pig slaughterhouses during the summer and autumn of 2014, in 10 Brazilian pig slaughterhouses during the summer and winter of 2009 and 10 Spanish ones during the spring and summer of 2007, respectively (Table 2). The same person assessing slaughterhouses in Spain was responsible for the training of assessors in Portugal, Italy, Finland and Brazil. The training courses consisted of the standardised courses of Welfare Quality®. This consisted of a three-day training course. The first day, measures were explained, with examples, by means of pictures and videos. The second day, a visit was made to a slaughterhouse and sampling methods and assessments under real circumstances were discussed. The third day, inter-observer reliability was assessed by means of videos/images and in comparison to the scores given previously by a gold standard. A gold standard in this case is the expert or group of experts who had developed a measure and prepared specific training material already scored for future assessors. Only those assessors obtaining a minimum of r=0.70 for all variables of the protocol were considered properly trained. The plants slaughtered between 20,000 and 2,000,000 pigs per year with a slaughtering speed of between 30 and 640 pigs per hour. The estimated time to carry out the assessment protocol was 5.50 h (Dalmau et al., 2009a) per slaughterhouse. However, in some cases this time increased up to 8 h when the observers had to wait for the arrival of a truck to assess the unloading. The WQ protocol was applied in several areas in the slaughterhouse, including the unloading area, lairage pens, corridors from lairage to the stunning area, the stunning area and post-stunning area (Table 1).

2.1. Unloading area

The welfare assessment started in the unloading area, where measures of general fear (reluctance to move and turning back), thermoregulation (panting and shivering), slipping and falling, lameness, sickness (defined as those animals unable to walk) and deaths of animals were assessed (Dalmau et al., 2009a; Welfare Quality, 2009; Table 1). After unloading, the length and width of 245 lorries were measured and the number of animals transported in the lorries was also counted to determine space allowance (Table 2). For a better comparison, this space allowance was harmonised to a weight of 110 kg. To do it, it was assumed that in Portugal, Finland, Brazil and Spain most of the animals were around the same weight, 110 kg. In the case of Italy, where animals were around 160 kg, the space was transformed to space per kg and then multiplied by 110 kg.

2.2. Lairage pens

In lairage, the length and width of eight pens in each slaughterhouse were measured and the number of animals counted (Table 2). Here again, for a better comparison, this space allowance was harmonised to a weight of 110 kg. The eight pens were selected randomly, but also taking into account the time of arrival of animals (i.e. selecting pens of animals that arrived at the lairage pen some hours or a few minutes before the assessment), the location in the plant (close or opposite to the entrance to the stunning system) and the size of the pen (when they were not homogeneous). The number of drinking points in each pen was counted (in the case of drinking nipples). Thermoregulation measures, such as huddling, shivering and panting, were assessed according to Welfare Quality (2009). Finally, dead animals were also recorded in these pens.

2.3. From lairage to stunning

The human-animal relationship was assessed by means of high-pitched vocalisations (HPV), defined as squealing or screaming, at the group level when animals were moved from lairage to the stunning area. It was noted if any animal vocalised in that way. Two types of measures were taken: The first one assessed whether any of the observed animals had vocalised or not during each 20 s interval (focal sampling). The second one was used to record if any of the pigs were vocalising just at the end of the 20 s interval (at Second 20, scan sampling). The sampling was repeated three times, of 4 min each (Welfare Quality, 2009), trying to assess at least two different farm batches. Therefore, the 20 s evaluation periods were carried out 12 times over a 4 min period, and this was repeated three times to give a total of 36 20 s evaluation periods.

2.4. Stunning area

To assess stunning effectiveness, the absence of corneal reflex (through physical stimulation of the cornea, being present when animals close their eyes after the contact; EFSA, 2004), rhythmic breathing (as indicated by a number of more than two respiratory movements within 36 s), righting reflex and vocalisations were assessed in 60 pigs per slaughterhouse, divided into three batches of 20 pigs each, trying to assess at least two different farm batches.

2.5. Post-stunning area

After slaughter, the presence (score 0: absence or 1: presence) of pleurisy and pneumonia, pericarditis and white spots in the liver was inspected in 60 animals per slaughterhouse, randomly selected in three groups of 20 animals each, trying to assess at least two different farm batches. Finally, skin lesions were also assessed on the carcass of 60 animals per slaughterhouse, divided into three batches of 20 animals

each (Welfare Quality, 2009). Three scores were used: score 0 (good carcass), score 1 (moderate damage), score 2 (severe damage), according to the method of Velarde and Dalmau (2012) and Welfare Quality (2009).

2.6. Statistical analyses

The slaughterhouses selected for the study may not give an accurate representation of the situation in each country. Therefore, the objective was not to compare countries, but rather to compare among different slaughterhouses located in specific countries. It is true that there are specific managements closely linked to one country, such as the body weight of the pigs assessed in the Italian slaughterhouses, which are by far bigger than those assessed in other countries are. However, this is a good example of why the results should not be used to compare among countries, as in Italy there are, as well, slaughterhouses killing animals of 110 kg that could have different results from those obtained in the present study for this country. In addition, as only one visit was performed per slaughterhouse, the statistical analysis is only descriptive. Nevertheless, statistical analysis by means of general models using the Proc Genmod procedure of Statistical Analysis System (SAS; software SAS Institute Inc.; Cary, NC; 1999–2001) was used to study the effect of the stunning system (electrical or gas) on the presence of HPV and stunning effectiveness. A negative binomial distribution was applied (Cameron and Trivedi, 1998) and significance was fixed at $P < 0.05$.

Unloading data, such as the presence of reluctance to move, turning back, slipping, falling, lameness, panting, shivering, sickness and deaths of animals, are presented as the percentage of animals observed. In addition, the presence of shivering, panting, huddling and animal death in the lairage pens was calculated as the percentage of animals found under these circumstances in relation to the total number of animals housed in the eight pens assessed in every slaughterhouse. Vocalisations are presented as the percentage of times of the event (presence of HPV) in relation to the 36 periods of 20 s that comprise the assessment. Measures to assess stunning effectiveness, carcass lesions and health measures in viscera are presented as the percentage of animals positive for every measure in relation to all 60 animals, carcasses or viscera assessed for each type of measure, respectively.

3. Results and discussion

3.1. Unloading area

Fear is an emotional state induced by the perception of a threatening or a potentially threatening situation (Boissy, 1995), and it involves physiological and behavioural changes that prepare the animal to cope with the danger (Forkman et al., 2007). These behavioural changes include reluctance to move or turning back, which can be used to assess fear during unloading (Dalmau et al., 2010). 10,616 pigs were assessed for general fear. In mean percentages, 4.36% and 4.95% of pigs showed reluctance to move and turning back, respectively. The range for reluctance to move was 0% (in 9 slaughterhouses) to 37.5%, and in the case of turning back it was 0% (4 slaughterhouses) to 21% (Fig. 1). According to Dalmau et al. (2009a, 2009b), reluctance to move is associated with the facilities, specially angle and slope of the unloading ramps, whereas turning back is mainly due to handling, usually associated with the driving of large groups of animals in the unloading area. Therefore, it seems that in the slaughterhouses assessed in Europe there was a problem of management while in the slaughterhouses assessed in Brazil the problem was more related to facilities (Fig. 1).

Ease of movement is assessed through the percentage of animals slipping and falling, and it is associated with inappropriate facilities for handling that compromise welfare (Grandin, 2003). 11,415 pigs were assessed for slipping/falling, and in mean percentages, 13.9% and 2.1% of pigs slipped and fell, respectively. However, the range for slipping ranged from 0.4% (no slaughterhouse obtained a 0% for this variable) to 57%, and for falling between 0% (7 slaughterhouses) and 13% (Fig. 2), so a great variability was found among plants, showing that there is room for improvement in this parameter.

Pigs are severely stressed during loading, transport and unloading, and the excitement associated with handling can lead to serious welfare problems and even death (Dalmau et al., 2009a). Sometimes, transport situations produce signs of shock in animals (i.e. Porcine Stress Syndrome or exhaustion) or animals with extreme lameness that are not able to walk by themselves. All of these cases are included in the category “sick animals” in the Welfare Quality® protocol. A mean percentage of sick animals around 0.30% and death of animals around 0.20% were found during the assessments (n=32902 pigs; Table 3). In fact, 198 out 245 (81%) and 222 out 245 (91%) of the lorries arrived with no sick or dead animals at the slaughterhouse. The maximum number of animals assessed as sick or dead in the same lorry (around 220 pigs transported) were 4 and 3, respectively. In Italy, the assessed animals were in a Protected Denomination of Origin brand of Parma Ham (heavy pigs) that imposes a high standard of care. Here, the sick animals parameter was very close to 0%, so it seems possible to reduce the percentages of sick animals at arrival. However, if this is a specific effect of the certification scheme, it should be confirmed in the same slaughterhouse by comparing animals for the non-Parma Ham market and animals for the Parma Ham market. In any case, taking into account the low percentages of animals assessed as sick or dead, any truck with more than one animal under either one or both situations should be studied in detail by the food-business operator to detect the risk factors that could explain the prevalence found.

The WQ protocol assesses, as well, lame animals able to walk by themselves, divided in this case into moderate or severe cases. 10,871 pigs were assessed for lameness, and in mean values, 3.0% and 0.4% of the pigs were scored as moderately or severely lame, respectively. Nevertheless, the range for moderate lameness was 0% (6 slaughterhouses) to 13.8%, and in the case of severe lameness it was 0% (28 slaughterhouses) to 6.2% (Fig. 3). In this case, seven slaughterhouses can be seen (all of them in Brazil) with high percentages of animals with moderate lameness when compared to the other slaughterhouses. According to the Brazilian assessors, this is related to the poor floor conditions of some farms at the end of the growing period, but this

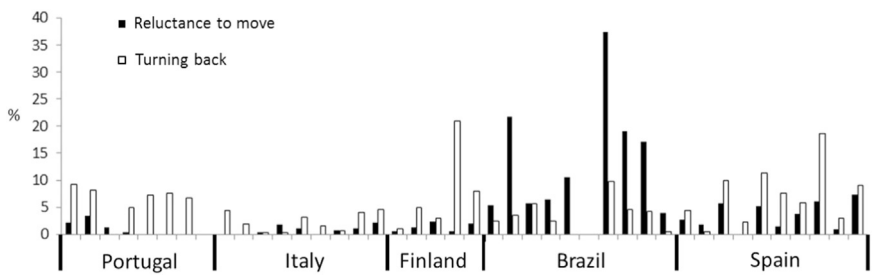

Fig. 1. Percentage of animals showing reluctance to move and turning back at the unloading area in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a slaughterhouse.

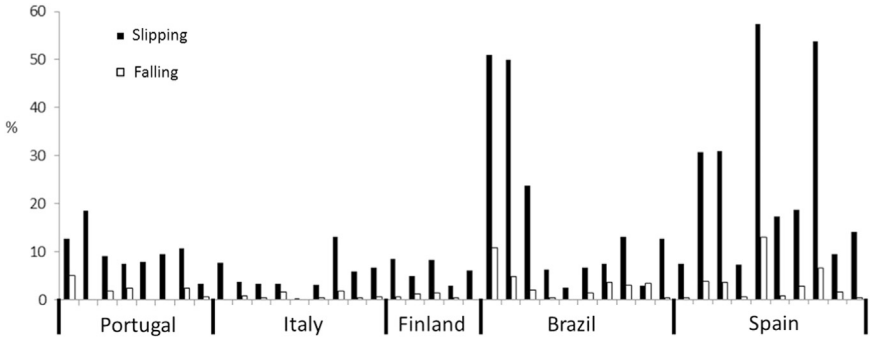

Fig. 2. Percentage of animals slipping and falling at the unloading area in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a slaughterhouse.

Table 3
Percentage ± SD of animals assessed as sick, dead or panting upon arrival at pig slaughterhouses in Portugal (8 slaughterhouses), Italy (9), Finland (5), Brazil (10) and Spain (10).

	Sick animals (%)	Dead animals (%)	Panting (%)
Portugal mean	0.11 ± 0.53	0.07 ± 0.33	0.02 ± 0.17
N=5347 max*	0.24 ± 0.39	0.22 ± 0.37	0.22 ± 0.37
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Italy mean	0.01 ± 0.13	0.00 ± 0.00	0.03 ± 0.26
N=7252 max	0.12 ± 0.30	0.00 ± 0.00	0.26 ± 0.64
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Finland mean	0.12 ± 0.37	0.06 ± 0.27	1.78 ± 6.05
N=4838 max	0.26 ± 0.30	0.15 ± 0.42	3.40 ± 10.98
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Brazil Mean	0.43 ± 0.72	0.05 ± 0.22	0.62 ± 1.06
N=5450 max	0.95 ± 1.23	0.30 ± 0.47	3.26 ± 2.26
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Spain Mean	0.30 ± 0.96	0.20 ± 0.73	1.03 ± 4.70
N=10,015 max	0.53 ± 0.83	0.68 ± 0.96	8.36 ± 6.62
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Total N= 32,902	0.20 ± 0.65	0.09 ± 0.42	0.69 ± 3.39

* Max (maximum) and min (minimum) percentage found per slaughterhouse.

should be confirmed by a specific study on these farms to assess such risk factors.

32,902 pigs were assessed for thermoregulation according to Welfare Quality (2009). No animal showed shivering on arrival at the slaughterhouse, even in animals assessed during winter in Brazil (minimum temperatures from 8 °C to 12 °C). A mean of 0.69% of the animals were panting (Table 3), although in 197 out of 245 lorries (80%), no animals were panting. The high mean percentage of animals panting in Finnish slaughterhouses, when the results found in other countries were seen, highlights the need for controlling hot thermal stress, even in cold climates, during the warm season. During late spring, summer and early autumn in warm countries, animals are usually unloaded in the cooler hours of the day (i.e. first hour of the day in the morning (7:00 to 9:00 a.m.) or at night), so problems of thermal stress and panting are reduced. Finally, some variability in the space allowance for pigs during transportation was found as well. The mean space allowance (m^2/110 kg animal) in the lorries was around 0.48 m^2, 0.51 m^2, 0.57 m^2, 0.54 m^2 and 0.46 m^2/animal in Portugal, Italy, Finland, Brazil and Spain, respectively, ranging from 0.27 m^2 (one lorry in Portugal and another in Brazil) to 1.15 m^2/animal (one lorry in Brazil, Fig. 4).

3.2. Lairage pens

12,006 pigs were assessed in the lairage pens. Fig. 5 shows a great variation between slaughterhouses regarding pen size. The mean value was 35 animals per pen, and the range was from five to 230 animals per pen. The lowest numbers of animals per pen were recorded in Italian slaughterhouses (mean=19) and the highest in Brazil (mean=59) and Spain (mean=44). In Italian slaughterhouses, due to the inclusion of the animals assessed in the Protected Denomination of Origin brand of Parma Ham, pen-groups on the farm were maintained both in lorry and in lairage, so the number of animals per pen was lower than were those found typically in other slaughterhouses. According to Rabaste et al. (2007), pigs kept in large groups (30 animals) spend more time standing and fighting, and are involved in more agonistic interactions (bites and head knocks) than are pigs lairaged in small groups (10 pigs). On the other hand, according to Grandin (2000), in US slaughter plants, mixing a large group of animals, of 200 or more from three or four different farms, resulted in less fighting than when mixing smaller groups of six to 40 pigs. However, according to Faucitano (2010), space allowance has a bigger impact on pigs' social behaviour than does group size. In fact, animals must have enough space for lying in a comfortable posture or for moving to the drinking points or to perform specific behaviours such as exploration (Velarde and Dalmau, 2012). In the present study, the mean space allowance was around 0.71 m^2, 0.63 m^2, 0.66 m^2, 0.75 m^2 and 0.53 m^2/110 kg animal in Portugal,

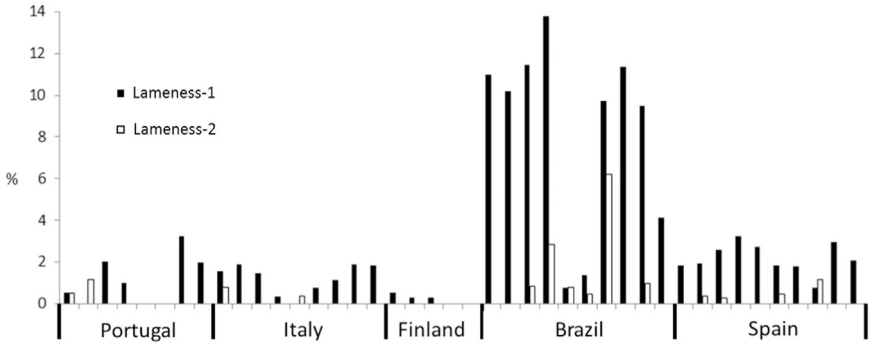

Fig. 3. Percentage of animals showing moderate or severe lameness after the arrival in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a slaughterhouse.

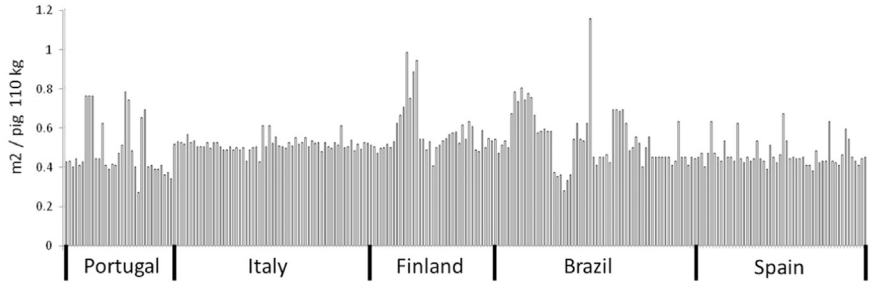

Fig. 4. Space allowance (m^2/animal) in the 245 lorries assessed in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a different truck.

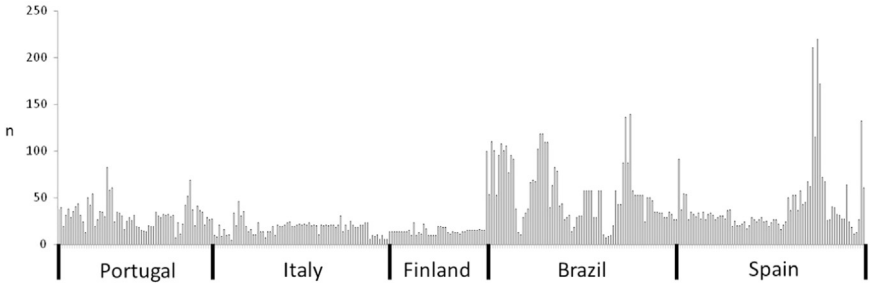

Fig. 5. Number of animals per pen in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a different pen (n=232).

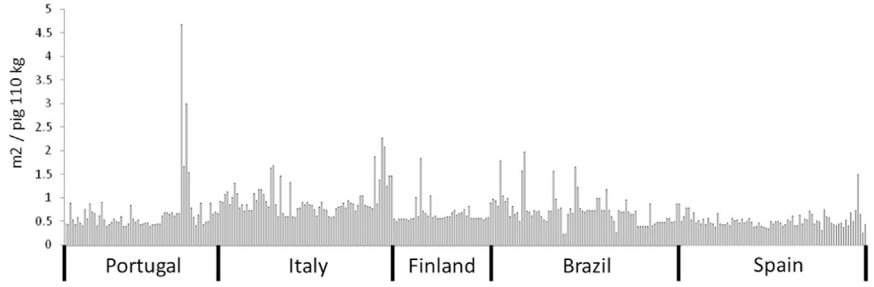

Fig. 6. Space allowance (m^2/animal) per pen in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a different pen (n=232).

Italy, Finland, Brazil and Spain, respectively (Fig. 6). Therefore, it was, in most cases, between the 0.47 m^2/ animal of 110 kg given by Weeks (2008, 235 kg per m^2) in the case of short lairage periods, and 0.73 m^2/ pig of 110 kg recommended by the same author for periods longer than 3 h. Nonetheless, a great variability was found for specific cases, ranging from 0.23 m^2 (one pen in Brazil) to 4.68 m^2/animal (one pen in Portugal).

The animals/drinkers mean ratio was 21, although the ratio differed from 1 to 69 animals per drinker (Fig. 7). The mean ratio was of 18, 13, 12, 5 and 25 in the slaughterhouses of Portugal, Italy, Finland, Brazil and Spain, respectively. The suggestion of Welfare Quality is to provide one drinker for every 10 animals (Welfare Quality, 2009). In this case, in all pens assessed in Brazil (100%), there were up to 10 animals per drinker. However, the percentage of pens with up to 10 animals per drinker was 13% in Portugal, 36% in Italy, 45% in Finland and 3% in Spain.

When the environmental temperature is too high, animals can show panting, and when it is too low they show shivering to increase body temperature (Huynh et al., 2005). In the case of low temperatures, pigs can also perform social thermoregulation behaviour, such as huddling, in which pigs are lying with over 50% of their body in contact with other pigs to maintain their body temperature (Velarde and Dalmau, 2012). When signs of thermoregulation were studied, those related to cold conditions were found more often (shivering and huddling) than were those related to warm conditions (panting; Table 4). Huddling was the most common behaviour shown of the three parameters assessed, with a mean of 3.76% of the animals lying on top of each other. Shivering was only found in Finland and Brazil. In the case of Brazil, an inappropriate use of showers (too much time with water too cold) left the animals wet for long periods of time and, in consequence, they showed these behaviours associated with cold conditions. According to Honkavaara (1989), lairage conditions of 15–18 °C and 59–65% relative humidity are recommended for pigs to facilitate comfort when resting. However, wet (more loss of heat) or dry (less loss of heat) animals or the presence (more loss of heat) or absence (less loss of heat) of wind can interfere in these values and must also be considered. Panting was not recorded in any slaughterhouse of Portugal or Italy. However, in Spain, Finland and Brazil, pigs panting were recorded in 0.16%, 0.17% and 0.33% of all of the animals assessed.

In the present study, only one pig was found dead among the 12,698 assessed (0.008%) in the selected pens of the 42 slaughterhouses. A complementary measurement not present nowadays in the Welfare Quality® protocol could be the inclusion of the animals housed in hospital or emergency pens.

3.3. From lairage to stunning

It has been stated that in pigs (in challenging conditions), the frequency and intensity of vocalisations (squeals/screams) can be a measure of the animal's inner state and thus serve as an indicator of a poor human-animal relationship (Weary et al., 1997; Grandin, 2001).

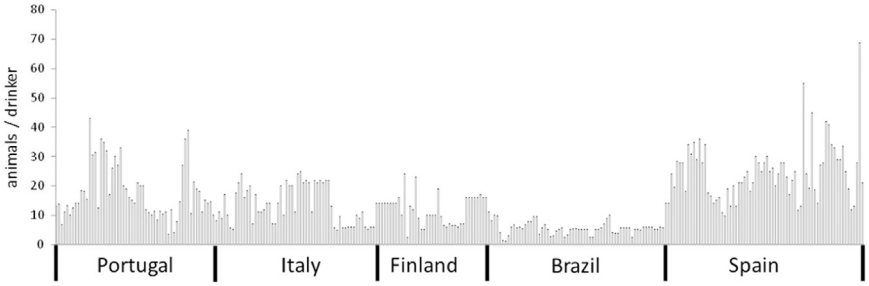

Fig. 7. Number of animals per drinker per pen in plants from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). Each bar represents a different pen (n=232).

Table 4
Percentage ± SD of animals panting, shivering and huddling at the lairage pens in pig slaughterhouses in Portugal (8 slaughterhouses), Italy (9), Finland (5), Brazil (10) and Spain (10).

	Panting (%)	Shivering (%)	Huddling (%)
Portugal mean	0.00 ± 0.00	0.00 ± 0.00	3.00 ± 0.74
N=2105 max*	0.00 ± 0.00	0.00 ± 0.00	4.69 ± 1.36
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Italy mean	0.00 ± 0.00	0.07 ± 0.12	5.01 ± 1.50
N=1336 max	0.00 ± 0.00	0.63 ± 1.77	11.36 ± 7.36
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Finland mean	0.17 ± 0.16	3.05 ± 1.26	8.14 ± 1.80
N=590 max	0.89 ± 2.53	14.54 ± 16.48	18.37 ± 6.97
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Brazil mean	0.33 ± 0.61	4.70 ± 0.83	0.40 ± 4.19
N=4482 max	1.01 ± 1.41	2.86 ± 7.14	15.26 ± 15.95
Min	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Spain mean	0.16 ± 0.37	0.00 ± 0.00	2.26 ± 0.85
N=3493 max	1.73 ± 1.85	0.00 ± 0.00	5.09 ± 4.62
Min	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.62
Total N=12,006	0.10 ± 0.36	1.63 ± 0.61	3.76 ± 2.40

* Max (maximum) and min (minimum) percentage found per slaughterhouse.

In the slaughterhouses, the presence of HPV during handling is used to assess the relationship between humans and animals (Algers et al., 2009). When this human-animal relationship was assessed in our slaughterhouses by means of HPV, results differed between them (Fig. 8). Dalmau et al. (2009a) stated that a relationship can exist between the stunning system and this parameter, as in some slaughterhouses, when using CO_2, animals are moved to the stunning area with automatic doors that reduce the human-animal interaction and thereby HPV. Actually, in the present study, when results were compared in relation to the stunning system (23 out of 42 slaughterhouses used electrical stunning and 19 used CO_2 at high concentrations), significant differences were found for periods with vocalisations throughout the whole 20 s (chi-square=142.8; d.f.=124, P=0.0059; 23 out of 36 being for CO_2 and 28 out of 36 for electrical, respectively) and periods with vocalisations just at the 20th second of each period (chi-square=144.0; d.f.=124; P=0.0012; 7 out of 36 being for CO_2 and 11 out of 36 for electrical, respectively). Therefore, this association is confirmed between vocalisations and the stunning system when assessed just before the stunning. However, as mentioned previously, the results can depend more on the way the animals enter the system than on the system itself (i.e. use of automatic doors vs use of an electric prod).

3.4. Stunning effectiveness

Stunning before slaughter is a statuary requirement in Europe (EC Reg. 1099/2009) and is performed to induce unconsciousness and insensibility in animals so that the slaughter can be performed without causing the animals any avoidable anxiety, pain, suffering or distress (EFSA, 2004). The four measures used to assess stunning effectiveness were the absence of corneal reflex, rhythmic breathing, righting reflex and vocalisations (Velarde et al., 2000; EFSA, 2004). Of the four measures used to assess stunning effectiveness, the least recorded indicators were vocalisation (20 out of 8100 animals; 0.2%) and righting reflex (120 out of 8100 animals; 1.5%). In contrast, 5.7% of pigs had corneal reflex (460 out 8100) and 4.7% of animals had rhythmic breathing (377 out 8100). In fact, the presence of the first two indicators is associated with a fully conscious animal. In contrast, the other two parameters show that the animal is just recovering consciousness at the moment of the assessment (EFSA, 2004). In most of the cases, the percentage of animals with corneal reflex was higher than was the percentage of animals with rhythmic breathing. However, this was not the case in some slaughterhouses with electrical stunning, where corneal reflex, especially in the first phases after stunning (when tonic and clonic phases occur), is difficult to assess (EFSA, 2004). In the heavy-weight pigs slaughtered in Italy with CO_2 stunning, it was found that a great percentage of animals had their eyes closed after stunning, and that impaired the performing of the corneal reflex test. In fact, according to OIE: “corneal reflex is difficult to verify and is often confounded with the palpebral reflex, which can be considered a false-positive. Thus, it must not be assessed in isolation” (OIE, 2015).

Animals with signs of recovery (corneal reflex and/or rhythmic breathing) ranged from 0% to 90% depending on the plant, showing a high variability among slaughterhouses (Fig. 9). Twenty-seven out of 42 slaughterhouses had more than 10% of positive for animals in one or both parameters and in only four slaughterhouses a 0% (100% of animals with no sign of recovery of consciousness) was obtained for both. The slaughterhouse with the worst results was a Brazilian one with 90% of animals recovered. The problem was a very long time from stunning to sticking using only head electrical stunning. This is a reversible system, and the animal recovers consciousness after around 40 s if sticking is not performed within the first 20 s after stunning (EFSA, 2004). In these cases, to move the sticking previously in the line or change to a head to body electrical system (irreversible system stopping the heart; EFSA, 2004) could solve the situation. When electrical or CO_2 stunning was compared, significant differences were found for rhythmic breathing (chi-square=135.7; d.f.=124, P=0.0063, with a mean value of 9.3% for CO_2 stunning and 18.2% for electrical stunning), indicating that gas stunning can be more effective in maintaining a state of unconsciousness in pigs than can the electrical one under commercial conditions.

3.5. Post-stunning area

Skin lesions can be assessed in the carcasses after slaughter. The number of skin lesions reflects the quality of the animal's physical and social environment (Gloor, 1986) and, in fact, could give valuable information about the management of animals in the farm of origin, during transport or in the lairage pens. Nevertheless, fresh lesions (object of the evaluation) are more likely to refer to transport and lairage. The best result for a slaughterhouse is to obtain a high number of carcasses assessed with a 0, and as few as possible with a 2. Carcasses with a score of 0 ranged from 0% to 78% and carcasses with a score of 2 ranged from 0% to 48%, depending on the slaughterhouse (Fig. 10). Carcasses with the intermediate score (1), ranged from 23%

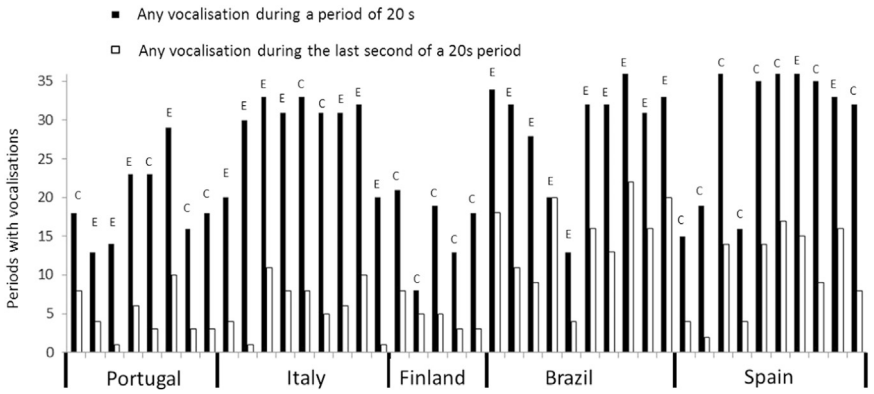

Fig. 8. Number of periods out of 36 with any vocalisation of a pig at any moment during the period or with a vocalisation just at the last second of the period while moving the animals from lairage to the stunning system. Assessment made during 36 periods of 20 s each for a total time of 12 min per slaughterhouse. Values are shown by slaughterhouse: Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). The stunning system is also indicated: C (CO_2 stunning) and E (Electrical stunning).

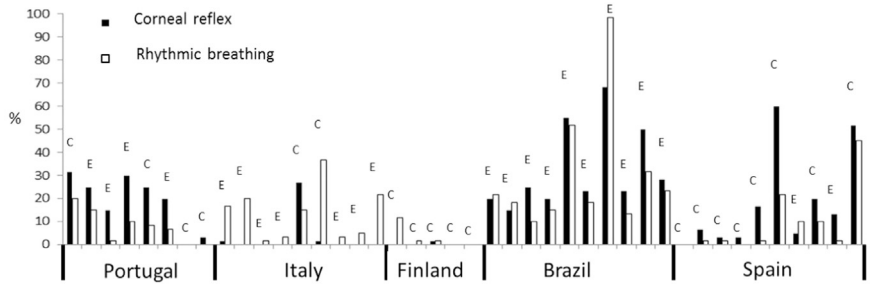

Fig. 9. Percentage of animals with the presence of corneal reflex or rhythmic breathing in pig slaughterhouses from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10). The stunning system is also indicated: C (CO_2 stunning) and E (Electrical stunning).

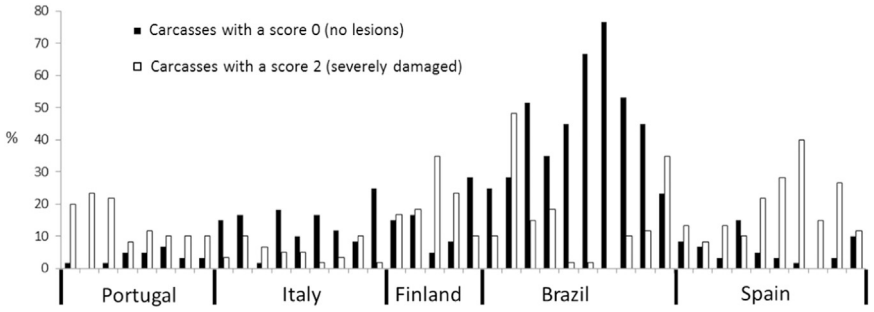

Fig. 10. Percentage of carcasses with score 0 (no lesions on the carcass) and with score 2 (severe damaged carcass) for skin lesions in pig slaughterhouses from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10).

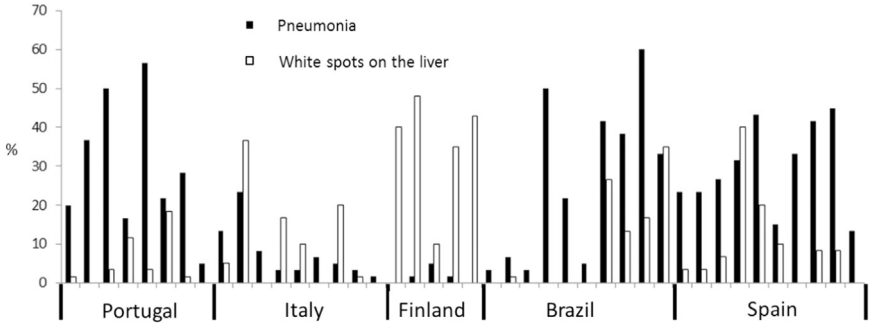

Fig. 11. Percentage of animals with pneumonia in the lungs and white spots on the liver based on slaughter-checks in pig slaughterhouses from Portugal (8), Italy (9), Finland (5), Brazil (10) and Spain (10).

to 88%, depending on the slaughterhouse. When assessed by country, it was found that percentages of score 0 were 3.3% in Portugal, 13.7% in Italy, 14.7% in Finland, 45.0% in Brazil and 5.7% in Spain. In contrast, the percentages of score 2 were 14.4% in Portugal, 5.2% in Italy, 20.7% in Finland, 15.2% in Brazil and 18.8% in Spain. In fact, the slaughterhouses assessed in Italy had very low percentages of carcasses scored with a 2, probably due to the fact that in Parma-Ham production, pigs are maintained in the same pen-group from the farm of origin during transport and at lairage, so mixing with unfamiliar animals and their consequences (fighting and lesions) is avoided. This shows that there is

Table 5
Suggested thresholds (maximum values in all cases except for space allowances, which are minimum values) for the different parameters of the best 10%, the best 30% and the best 50% in terms of welfare of the pigs based on evaluations of 52,468 pigs at slaughterhouses in Portugal (8), Italy (9), Finland (5), Brazil (10 and Spain (10).

Place	Measures	Best 10%	Best 30%	Best 50% 50%
Unloading	Reluctant to move, %	0	0.5	1.5
	Turning back, %	0	1.5	4
	Slipping; %	3	6	8
	Falling, %	0	0.4	0.8
	Lameness 1, %	0	0.5	1.8
	Lameness 2, %	0	0	0
	Sick animals, %	0	0	0
	Dead animals, %	0	0	0
	Shivering, %	0	0	0
	Panting, %	0	0	0
	Space allowance, m^2/ 100 kg	0.67	0.53	0.49
Lairage	Dead, %	0	0	0
	Panting, %	0	0	0
	Shivering, %	0	0	0
	Huddling, %	0	0	3
	Space allowance, m^2/ 100 kg	1.10	0.70	0.57
	Animals per drinker	5	8	13
Moving to stunning	Periods of vocalisations over 20 s	16/36	21/36	27/36
	Periods with vocalisations at 20 s	0/36	3/36	6/36
Stunning area	Corneal reflex, %	0	0	10
	Righting reflex, %	0	0	0
	Rhythmic breathing, %	0	0	5
	Vocalisations, %	0	0	0
Post-stunning	Pleurisy, %	0	0	5
	Pneumonia, %	0	5	15
	White spots on the liver, %	0	0	5
	Pericarditis, %	0	0	0
	Score 0 for lesions, %	50	20	10
	Score 2 for lesions, %	0	5	10

room for improvement for results in other types of slaughterhouses, not only in animal welfare but in carcass quality as well. The high percentages of animals with a score of 0 in Brazil (carcass without lesions) could possibly be explained, in part, by the smaller number of animals per drinker in Brazil (up to 10), when compared to the other slaughterhouses (ranging from 12 to 25), reducing the movement of animals after arrival when searching for water and the competition for resources such as drinkers. It would be interesting to study this factor in further studies.

In relation to health measures, the most prevalent problem was pneumonia, associated with respiratory problems, with a mean value of 21% of the animals affected, followed by white spots on the liver (14.5%; Fig 11), which indicate the presence of parasites (*Ascaris suum*) in the animals, pleurisy (12.7%) and, finally, pericarditis (3.3%). Although it is true that these problems are more associated with farm conditions than with conditions in the slaughterhouse, checking these problems in the slaughter-line offers the possibility of improving the conditions of certain farms, especially if the slaughter operators include these assessments into their working day and SOPs. In these cases, a good exercise of traceability and information from the slaughterhouse to the farm can result in future improvements on animal welfare.

3.6. Possible thresholds for future assessments

A system of thresholds for the assessment of animal welfare at the slaughterhouse has already been established in the past by Grandin (2010) and Grandin (2012a, b). In this case, the assessment consists as well, such as the Welfare Quality protocols, of the assessment of complementary aspects in different areas of the slaughterhouse: 1) Percentage of animals rendered insensible with one application of the stunner; 2) Assessment of insensibility; 3) Vocalisations; 4) Animals falling; 5) Use of electric prod, and 6) Acts of abuse. In contrast to the system used by Grandin (2010), already applied for over ten years, the Welfare Quality protocols have been very little used commercially (just a few in the last few years in Spain), so little information is available. However, the information provided in the present study can be useful to establish risk factors in animal welfare at different areas in the slaughterhouses and can be used to establish some thresholds of pre-alarm and alarm. This can be a first step for the development of a complete scoring system for the WQ protocol for pigs at the slaughterhouse, similar to what already exists for the protocol used at the farm level (Welfare Quality, 2009). Once the thresholds for each measure are defined (what could be considered correct and what not), the different variables can be combined to offer a final score, and this score would be used for certification purposes. The certification schemes on animal welfare can be a useful tool to improve animal welfare because the best companies can have access to specific markets demanding animal-friendly products, and the rest of the companies are pushed to move to higher standards than the minimum legal requirements. Nevertheless, as mentioned previously, after defining the measures to be assessed (in the present study, they were those developed by the WQ protocols), the critical thresholds should be defined for each one of these measures. One possible way to do this is to ask different experts to establish these levels according to their experience or even the limited literature existing in most of the parameters assessed in Welfare Quality protocols. The second one is based on the assumption that the 42 slaughterhouses assessed are providing enough data to have a good representation of the most possible scenarios and, in consequence, use these data to suggest the thresholds. However, both options are not mutually exclusive, as experts can be consulted as well, after checking the results of the 42 slaughterhouses assessed in the present study. According to the results, in Table 5 we suggest defining three levels for every parameter assessed. A first threshold could be considered to be those separating the 50% best from the 50% worst slaughterhouses for a parameter. A second threshold (enhanced slaughterhouses) could be considered for those in the top 30% of slaughterhouses. Finally, a threshold for excellence could be considered to be those representing the top 10% for any of the parameters. According to that, there are parameters such as severe lameness, sick, dead and animals with thermoregulatory problems at arrival or at the lairage pens, righting reflex and vocalisation after stunning and the presence of pericarditis that, even with the first threshold, should be 0. In other cases, with values different from 0, this classification allows one to maintain a system with different levels that can be readjusted after some time. Therefore, at the moment that more slaughterhouses are arriving at the thresholds of the top 10%, for instance, a new threshold can be considered and, as result, some companies are pushed to improve animal welfare to reach the new threshold to be at the top level. In this way, the certification scheme is a tool for communication with the consumer, but also, as well, a tool to improve animal welfare at the slaughterhouses. In addition, as mentioned previously, thresholds of pre-alarm and alarm could be defined. For instance, for the best 10%, the pre-alarm threshold could be defined at the alarm threshold of the best 30% and, accordingly, for the best 30%, the pre-alarm threshold defined at the alarm threshold of 50% (Table 5).

4. Conclusions

Most of the parameters assessed in the Welfare Quality® protocol for pigs at the slaughterhouse present enough variability among plants to offer the possibility to establish thresholds for the development of

future certification schemes. Nevertheless, even with a threshold allowing for the certification of 50% of the slaughterhouses as good plants, there are parameters that should present a prevalence of 0% according to the results obtained in 42 slaughterhouses of Portugal, Italy, Finland, Brazil and Spain.The use of electric stunning is associated with more vocalisations and animals showing rhythmic breathing as a sign of recovery of consciousness in higher percentages than when CO_2 is used to stun.

Acknowledgements

Part of this research was funded by the Welfare Quality® Project. This project was a European research project concerning the integration of animal welfare in the food-quality chain: from public concern to improved welfare and transparent quality. Welfare Quality® was co-financed by the European Commission, within the 6th Framework Programme, Contract no. FOOD-CT-2004–506508. This article represents the author's views and does not necessarily represent a position of the European Commission, which will not be liable for the use made of such information. Thanks are due to all of the slaughterhouse personnel, the food business and operators. Special thanks are given to Alyne van Ham and Victor de Abreu Lima for their contribution to data collection in Brazil and Joaquim Pallisera for his collaboration during the training of experts of different countries.

References

Algers, B., Nordensten, L., Velarde, A., 2009. Measuring high pitch vocalisations in pigs driven to slaughter at abattoirs. In: Assessment of Animal Welfare Measures for Sows, Piglets and Fattening Pigs (Edited by B. Forkman and L Keeling), Welfare Quality Reports 10, Cardiff University, Scotland.

Boissy, A., 1995. Fear and fearfulness in animals. Q. Rev. Biol. 70, 165–191.

Botreau, R., Veissier, I., Butterworth, A., Bracke, M.B.M., Keeling, L.J., 2007. Definition of criteria for overall assessment of animal welfare. Anim. Welf. 16, 225–228.

Botreau, R., Winckler, C., Velarde, A., Butterworth, A., Dalmau, A., Keeling, L., Veissier, I., 2013. In: Blokhuis, H., Miele, M., Veissier, I., Jones, B. (Eds.), Improving Farm Animal Welfare. Science and Society working together: The Welfare Quality approach.. Wageningen Academic Publishers, The Netherlands.

Cameron, A.C., Trivedi, P.K., 1998. Regression Analysis of Count Data. Cambridge University Press, Cambridge.

Dalmau, A., Fabrega, E., Velarde, A., 2009b. Fear assessment in pigs exposed to a novel object test. Appl. Anim. Behav. Sci. 117, 173–180.

Dalmau, A., Temple, D., Rodriguez, P., Llonch, P., Velarde, A., 2009a. Application of the Welfare Quality® protocol at pig slaughterhouses. Anim. Welf. 18, 497–505.

Dalmau, A., Geverink, N., Van Nuffel, A., Van Steenbergen, L., Van Reenen, K., Hautekiet, V., Vermeulen, K., Velarde, A., Tuyttens, F.A.M., 2010. Repeatability of lameness, fear and slipping scores to assess animal welfare upon arrival in pig slaughterhouses. Animal 4, 804–809.

EC, 2009. Council regulation (EC) No 1099/2009 on the protection of animals at the time of killing. Eur. Community Off. J. L303, 1–30.

EFSA, 2004. Welfare aspects of animal stunning and killing method, Scientific Report of the Scientific Panel of Animal Health and Welfare on a Request from the Commission Question. Adopted on the 15th of June 2004. Brussels ⟨http://www.efsa.eu.int/science/ahaw/ahaw_opinions/495/opinion_ahaw_02_ej45_stunning_report_v2_en1.pdf⟩

Eurobarometer, 2016. Special Eurobarometer 442, Report, Attitudes of Europeans towards Animal Welfare, ⟨http://ec.europa.eu/COMMFrontOffice/PublicOpinion⟩.

Faucitano, L., 2010. Invited review: effects of lairage and slaughter conditions on animal welfare and pork quality. Can. J. Anim. Sci. 90, 461–469.

Forkman, B., Boissy, A., Meunier-Salaün, M.-C., Canali, E., Jones, R.B., 2007. A critical review of fear tests used on cattle, pigs, sheep, poultry and horses. Physiol. Behav. 92, 340–374.

Gloor, P., 1986. Lesions on the integument – a mirror of behaviour and environment. Appl. Anim. Behav. Sci. 15, 194–195.

Grandin, T., 2000. Handling and welfare of livestock in slaughter plants. (Chapter 20)In: Grandin, T. (Ed.), Livestock Handling and Transport 409. CAB International, 439.

Grandin, T., 2001. Cattle vocalizations are associated with handling and equipment problems at beef slaughter plants. Appl. Anim. Behav. Sci. 71, 191–201.

Grandin, T., 2003. Good Management Practices for Animal Handling and Stunning 2nd ed.. AMI Meat Institute Foundation.

Grandin, T., 2010. Auditing animal welfare at slaughter plant. Meat Sci. 86, 56–65.

Grandin, T., 2012a. Auditing animal welfare and making practical improvements in beef-, pork- and sheep-slaughter plants. Anim. Welf. 21 (S2), 29–34.

Grandin, T., 2012b. Developing measures to audit welfare of cattle and pigs at slaughter. Anim. Welf. 21, 351–356.

Honkavaara, M., 1989. Influence of lairage on blood composition of pig and on the development of PSE pork. J. Agric. Sci. Finl. 61, 433–440.

Huynh, T.T.T., Aarnink, A.J.A., Gerrits, W.J.J., Heetkamp, M.J.H., Canh, T.T., Spoolder, H.A.M., Kemp, B., Verstegen, M.W.A., 2005. Thermal behaviour of growing pigs in response to high temperature and humidity. Appl. Anim. Behav. Sci. 91, 1–16.

OIE, 2015. Technical notes on welfare of red meat species in pre-slaughter and slaughter ⟨http://rpawe.oie.int/fileadmin/doc/eng/ToT_Training_material/Technical_notes_cattle_sheep_and_pigs_final.pdf⟩

Rabaste, C., Faucitano, L., Saucier, L., Foury, D., Mormède, P., Correa, J.A., Giguère, A., Bergeron, R., 2007. The effects of handling and group size on welfare of pigs in lairage and its influence on stomach weight, carcass microbial contamination and meat quality variation. Can. J. Anim. Sci. 87, 3–12.

Velarde, A., Dalmau, A., 2012. Animal welfare assessment at slaughter in Europe: moving from inputs to outputs. Meat Sci. 92, 244–251.

Velarde, A., Gispert, M., Faucitano, L., Manteca, X., Diestre, A., 2000. Survey of the effectiveness of stunning procedures used in Spanish pig abattoirs. Vet. Rec. 146, 65–68.

Weary, D.M., Ross, S., Fraser, D., 1997. Vocalizations by isolated piglets: a reliable indicator of piglet need directed towards the sow. Appl. Anim. Behav. Sci. 53, 249–257.

Weeks, C.A., 2008. A review of welfare in cattle, sheep, and pig lairages, with emphasis on stocking rates, ventilation and noise. Anim. Welf. 17, 275–284.

Welfare Quality®, 2009. Welfare Quality® Assessment Protocol for Pigs (Sows And Piglets, Growing and Finishing Pigs). Welfare Quality® Consortium, Lelystad, Netherlands.