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pH measurements in the slaughterline and carcass quality: a survey in six Belgian slaughterhouses

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Abstract

pH was measured early post mortem in longissimus muscle (and occasionally in semimembranosus muscle) in the slaughterline of six Belgian slaughtering plants in three or four sessions. Mean pH values differed according to the mode of expression: pH means calculated after transformation to hydrogen ion concentrations were always lower than means calculated directly from pH values. The difference was linearly dependent on the variance, meaning that transformation of pH values to hydrogen ion concentrations is strongly recommended when comparing mean values of groups with unequal variances. Large differences in pH means were found between slaughterhouses that could not be attributed to differences in time of measuring postmortem and that were probably not related to differences in the slaughtering procedure. On the other hand, negative relationships were apparent between carcass quality data (lean content and instrumental or visual conformation score) and pH values between as well as within all slaughtering plants. Although no exact information was available on the preslaughter treatment of the animals, it is suggested that the genetic antagonism between carcass quality and meat quality is the main source of the fairly high proportion of low initial pH values and inferior meat quality in Belgian slaughter pigs.

Keywords: pork quality, pH, PSE, carcass quality, slaughtering

Introduction

Production of slaughter pigs in Belgium is characterized by an intensive search for very lean animals. Within the European carcass classification grid (S-EUROP), more than eighty percent of the carcasses are in the S and E class, meaning that the mean estimated carcass lean content approximates sixty percent (Casteels, 1989). Furthermore, not only lean content but also conformation score of the carcass is of great value for the Belgian meat industry. Conformation score is one of the most important factors in price evaluation and marketing of carcasses or joints (Pauwels & Moermans, 1986). It refers to a visual appreciation of the width of ham and loin and the shape of the musculature.

In order to produce lean, well-shaped slaughter pigs with a high carcass value, the use of very meaty boar lines of the Piétrain or the stress-sensitive Belgian Landrace breed is very common in Belgium. Increasing carcass quality has been the first aim of selection for many years and less attention has been paid towards other production traits such as growth rate, fertility and meat quality (Lampo, 1987). The main drawback of this pork production system is the relatively high degree of stress sensitivity among the pig population, resulting in stress deaths during transport to the slaughterhouse and sensory meat quality defects (PSE-meat) (Lampo, 1980, 1984). Although numerous studies have been carried out in the past regarding the effect of stress sensitivity on meat quality and the occurrence of PSE-meat, less information is available on the relationship between carcass and meat quality measured on a large number of animals under practical circumstances. Generally, there seems to be a genetic antagonism between meat quantity and meat quality, although this relationship may strongly depend on the frequency of stress sensitivity of the population studied (Sellier, 1988; Matzke & Holzer, 1989; Cameron, 1990; De Vries et al., 1992; Hovenier et al., 1992; De Smet et al., 1993). In addition, pork quality is influenced by a number of non-genetic factors causing physical preslaughter stress (Warriss, 1987; Tarrant, 1989). It is often difficult to distinguish the effect of genetic and non-genetic factors on the development of meat quality defects. The aim of the present work was to study the relationship between carcass and meat quality under practical circumstances. Therefore, we conducted a survey in several Belgian slaughtering plants. As an index of meat quality, pH values in longissimus muscle were recorded shortly postmortem in the slaughterline and were related to instrumental or visual carcass classification data.

Materials and methods

Slaughtering plants

Six Belgian commercial slaughtering plants participated in the study. During the months October, November and December of 1992, plants I and II were visited each four times and plants III, V and VI were each visited three times. As far as possible, visits were spread from Monday to Friday. Plant IV was visited four times in February and March of 1993, always on a Wednesday. All plants are representative for the Belgian situation, but they differ in several aspects. Speed of the slaughterline ranges from approximately 100 pigs h^{-1} to more than 500 pigs h^{-1}. The mean number of pigs slaughtered per week during the period of study differed up to tenfold between the plants visited. To stun the animals, five plants use a restrainer and an automatic electric high-voltage apparatus, whilst in one plant (V) animals are stunned on the floor by means of manually served electric tongs. In plants I and V hanging preceeds sticking and bleeding whilst in the other plants sticking is done in a lying position. Hence, mean time difference between the end of the stunning phase and the moment of sticking is generally less than five seconds in four plants (II, III, IV, VI), it is between five and ten seconds in plant V and between 15 and 20 seconds in plant I. The side carcasses are hung up differs between plants and also within most plants.

In spite of these differences in the slaughtering procedure between plants, most aspects were very similar and no aberrant situations were seen in one or another plant.

pH measurements

pH was measured in the *M. longissimus thoracis* (LT) around the 13th vertebra at a depth of approximately 2.5 cm (pH_1) using a portable Knick pH-meter (model Portamess 654, Knick, Berlin, Germany) and an Ingold Xerolyt electrode (model LOT 406-M6-DXK-S7, Ingold, Urdorf, Switzerland). The electrode had to be replaced several times due to breaking. Calibration was performed before each session. pH was measured in the right carcass side in all slaughterhouses except for plant III (left carcass side). Depending on the speed of the respective slaughterline, all carcasses or every second or third carcass were measured. Each session lasted approximately three to four hours. On different sessions within each plant, measurements were started on a different moment of the day when possible.

In plants IV and VI, pH was also measured in the semimembranosus muscle (SM) on part of the animals, immediately following pH_1 measurement in LT. Therefore, a Knick Portamess 654 pH-meter and an Ingold Xerolyt electrode was used in plant IV and a NWK Thien pH meter (model pH-K21, NWK Thien, Landsberg, Germany) in plant VI. Measurements with the NWK Thien pH-meter were conducted by the slaughterhouse staff.

Since we were constrained by the respective slaughtering facilities, it was impossible to measure pH at a standardized time postmortem for all plants. Time between sticking of the animal and measuring pH (T_{pH}) was checked in each plant on several occasions. T_{pH} was 20–25 minutes in plants I, II and III, 25–30 minutes in plant V, 30–35 minutes in plant VI and 35–40 minutes in plant IV. Within each plant, these time limits may be considered as rather constant although slight deviations may occur.

Carcass grading and other data

Either instrumental or visual grading of the carcasses or both was performed. Instrumental grading in Belgium is done by means of the SKGII-device (Casteels, 1989). Four physical measurements (loin fat thickness, ham width, waist width and ham angle) are combined into an estimate of the carcass lean content and a conformation score (the lower the value, the better the conformation). On the other hand, visual carcass classification is still widely used in Belgium. The following trade classes are distinguished:

EE and E, especially good from all points of view,
AA, very good conformation and lean,
I A, good conformation and lean,
II A, good conformation and average fat,
III A, good conformation and very fat,
I B, inferior conformation and lean,
II B, inferior conformation and average fat,
I C, poor conformation and lean.

According to Pauwels & Moermans (1986), the following numeric values can be attributed to the respective classes corresponding to the actual market value differences: EE, 190; E, 160; AA, 130; I A, 100; II A and I B, 70; III A, II B and I C, 40. This numeric, economic expression of the visual classification is referred to as the carcass quality index (CQI).

In plants II, IV and VI both instrumental (lean content and conformation score) and visual classification data were available, except conformation score in plant VI. Plants I and III only performed instrumental and visual grading, respectively, whilst in plant V part of the carcasses were classified instrumentally and part were classified visually. Warm carcass weight (WCW) was also measured.

Carcasses could be assigned to different groups of origin. Animals are normally marked before transport or upon delivery at the slaughterhouse. A different mark generally corresponds to a different farm of origin and, consequently, to a different transportation distance and time. In a few cases, the same mark may have been given to animals originating from different farms, i.e. animals that were collected and delivered by a trader. Origin of the animals and transportation distance or time was normally not known, although it may be accepted that distances longer than 100 km seldomly occured. According to limited information of the staff of the respective plants, mean transportation distance was probably not very different between plants, except for slaughterhouse V that received pigs from the immediate surroundings. On the other hand, waiting time before slaughter was known for most animal groups. A resting time of at least two hours is generally recommended in order to allow the pigs to recover from transport and unloading stress (Eikelenboom, 1989). This was only practised to a large extent in plant I, causing the highest mean waiting time in this plant. In the other plants, more than forty and up to eighty percent of the animals were slaughtered within two hours after arrival. Mean waiting time was clearly lower in plant V compared to the other plants. On the other hand, environmental stress might have been smaller in this relatively small plant. Data concerning time of feed withdrawal before transport, loading density, the way of driving and handling and possible treatment with sedatives etc. were not available. Again, in spite of the aspects mentioned, information from the slaughterhouses' staff did not suggest that one plant was really different from the others regarding the way pigs were handled before slaughter. Variability in these preslaughter factors was higher between batches within plants than between plants.

Calculations

Since the SKGII-device only operates within a certain carcass weight range and since we were only interested in normal slaughtering pigs, all carcasses weighing less than 60 kg and more than 110 kg were excluded. No other selection of the carcasses was made, except in plant IV where some carcasses (mostly very fat) already left the slaughterline to a chilling room before the site of pH measurement.

Calculation of mean pH values was done both on measured pH_1 values and on pH_1 values transformed to hydrogen ion concentrations. Mean hydrogen ion concentrations were then transformed back in order to obtain mean pH_1 values.

Pork quality categories based on pH_1 LT values were considered as follows : PSE-meat, pH_1 LT < 5.6; questionable meat quality, 5.6 < pH_1 LT < 5.8; good meat quality, pH_1 LT > 5.8 (Kallweit, 1981; Casteels & Bosschaerts, 1986; Matzke et al., 1991). It must be emphasized that a classification in meat quality categories based on pH_1 values is arbitrary. Muscle pH_1 and other pork quality parameters are continuous variables. Hence, a division in quality groups according to the proposed boundaries may at best offer a rough indication of the variability in ultimate meat quality. Carcasses showing a pH_1 value lower than 5.6 will almost certainly develop all PSE characteristics, whilst the probability that carcasses having a pH_1 value higher than 5.8 do not show meat quality defects is also rather high. Carcasses with intermediate pH_1 values (5.6–5.8) are very likely to develop one or several of the PSE characteristics.

Since the time of measuring postmortem pH was not standardized across plants, mean pH_1 values and number of carcasses in each quality group are not strictly comparable between plants. Hence, only descriptive statistics were performed and no statistical tests were carried out to detect differences between slaughterhouses.

Results

The data were obtained from 11383 animals. Overall mean (± sd) WCW was 87.8 (± 9.2) kg. Mean WCW differed by no more than 5 kg between slaughterhouses (Table 1). Small but significant positive correlations between pH_1 LT values and WCW were found in five out of the six slaughterhouses (r maximum = 0.134).

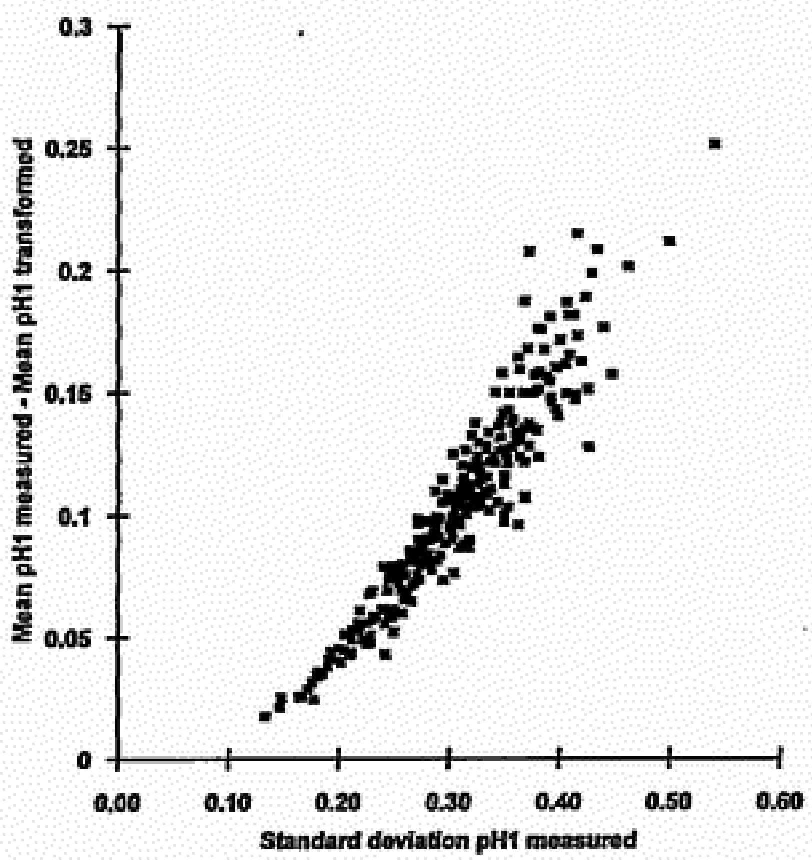
Large differences in carcass and meat quality between plants can be seen (Table 1). It should be mentioned that mean pH values differ according to the method of calculation. The most correct method, logarithmic transformation of the mean H+ ion concentration, always yields lower mean pH values compared to the usually performed direct calculation of the mean of the measured pH values. In logarithmic transformation the higher pH values have less influence on the mean, so this finding is not related to the nature of the data but has simply a theoretical background. However, differences in mean pH_1 LT due to the method of calculation were not equal across slaughterhouses and mainly depend on the variance. The difference ranged from 0.09 to 0.18 between plants. When calculating mean pH_1 LT of animal groups using both methods (n = 270, groups consisting of 5–201 animals), mean (± sd, range) difference was .10 (± 0.04, 0.02-0.25). The strong linear dependency of the difference on the variance of these cases is shown in Figure 1. Hence, transformation of pH values is strongly recommended when comparing groups with unequal variances.

Both methods of calculation revealed large differences in mean pH_1 LT between plants. As mentioned before, mean pH_1 values are not really comparable across plants due to differences in T_{pH}. However, plants IV and VI had the lowest and highest mean pH_1 LT respectively, although mutual difference in T_{pH} was lower compared to the other plants. On the other hand, a negative relationship between mean pH_1 LT and carcass quality across slaughterhouses was more apparent. Inferior car-

Table 1. Meat quality (pH_1 LT) and carcass quality in six slaughterhouses.

Plant		I	II	III	IV	V		VI
Number of observations		1885	2525	1584	2435	576	371	2043
				Meat quality				
T_{pH} (minutes)		20–25	20–25	20–25	35–40	25–30	25–30	30–35
pH_1 LT (measured)	Mean	6.26	6.08	6.14	5.88	6.08	6.10	6.30
	SD	0.40	0.32	0.30	0.30	0.38	0.41	0.36
Mean pH_1 LT (transformed)		6.09	5.97	6.03	5.79	5.92	5.92	6.15
pH_1 LT < 5.6 (%)		3.5	6.7	4.5	20.1	13.9	12.1	3.2
5.6 < pH_1 LT < 5.8 (%)		11.8	15.5	12.3	21.0	13.2	19.4	8.1
pH_1 LT > 5.8 (%)		84.7	77.8	83.1	58.9	72.9	68.5	88.7
				Carcass quality				
Warm carcass weight (kg)	Mean	88.2	87.7	90.4	86.2	85.8	87.2	88.2
	SD	8.9	9.6	10.3	8.1	8.4	9.0	9.4
Lean content (%)	Mean	60.1	59.3		62.7		61.9	55.7
	SD	3.4	3.1		2.7		2.5	4.4
Conformation score	Mean	1.90	2.03		1.52		1.78	
	SD	0.52	0.52		0.51		0.45	
Carcass quality index *	Mean		84	84	120	89		71
	SD		31	30	37	28		26

* Numeric expression of the visual carcass classification



Linear regression:
Difference = −0.077 + 0.588 × standard deviation
r = 0.947, n = 270

Figure 1. Linear dependency of the difference between mean pH_1 LT values calculated directly from measured pH_1 LT values or after transformation to H^+ ion values on the standard deviation of measured pH_1 LT values.

cass quality as present in plant VI was associated with the highest pH_1 LT values and the lowest proportions of PSE meat and questionable meat quality. Contrary, plants IV and V showed both the highest carcass quality standards and the highest proportions of PSE-meat and questionable meat quality. Nevertheless, comparable mean values for carcass quality in plants I, II and III were accompanied by some differences in mean pH_1 and proportion of PSE meat, in spite of identical measuring times post-mortem. Due to the unknown origin of the animals and multiple differences in the slaughtering circumstances in these plants, it is impossible to explain this variability in mean pH_1 by one or more genetic or non-genetic factors.

An inverse relationship between meat quality and carcass quality was also apparent within each slaughterhouse (Table 2 and 3). Significant negative and positive correlation coefficients between pH_1 LT and lean content and pH_1 LT and conformation score respectively were found in all plants that used the SKGII device. Within each of these plants, pH_1 LT was better related to conformation score than to lean content. In spite of the discontinuous nature of the visually determined CQI, pH_1 LT was fairly well related to this parameter in the plants that perform visual carcass grading. When both instrumental and visual classification is applied to the same carcasses (plants II, IV and VI), it is obvious that pH_1 *LT* is better related to CQI than to lean content. For comparison, mean pH_1 LT values following both methods of calculation according to carcass category and plant are given in Table 3. Within each plant, there is a steady increase in mean pH_1 LT values from categories EE+E and AA over A to B.

pH_1 measurements in LT and SM in plants IV and VI are compared in Table 4. Whilst mean pH_1 differed by 0.2 pH units between LT and SM in plant IV, almost no difference was found in plant VI. It has to be remembered that the pH-meter used in SM in plant VI was of another type, but it was never checked to what extent this might have influenced the pH values. On the other hand, the correlation between pH_1 values in LT and SM was higher in plant VI compared to plant IV. Correlation coefficients were too low to allow prediction of pH_1 values in SM by measurements in

Table 2. Linear regressions of pH_1 LT with lean content, conformation score and carcass quality index in six slaughterhouses.

Plant		I	II	III	IV	V		VI
Number of observations		1885	2525	1584	2435	576	371	2043
Lean content (%)	k* (x10)	−0.163	−0.177		−0.264		−0.363	−0.151
	r**	−0.136	−0.177		−0.238		−0.221	−0.183
Conformation score	k	0.193	0.206		0.227		0.208	
	r	0.248	0.339		0.383		0.226	
Carcass quality index	k (x100)		−0.304	−0.166	−0.218	−0.333		−0.453
	r		−0.295	−0.155	−0.264	−0.245		−0.329

* Regression coefficient. All regression coefficients are highly significant (P<0.001)
** Correlation coefficient

Table 3. Mean ± SD measured pH_1 LT (first row) and mean pH_1 LT after H^+ ion transformation (second row) according to carcass trade class and plant (number of observations between brackets).

Plant	II	III	IV	V	VI
EE + E	5.76 ± 0.22 5.71 (72)	5.92 ± 0.25 5.85 (23)	5.79 ± 0.24 5.73 (617)	5.84 ± 0.29 5.76 (12)	5.77 ± 0.17 5.74 (7)
AA	5.93 ± 0.29 5.84 (215)	6.06 ± 0.32 5.95 (162)	5.86 ± 0.29 5.77 (623)	5.90 ± 0.33 5.79 (85)	6.02 ± 0.33 5.90 (142)
I A	6.04 ± 0.30 5.94 (1048)	6.13 ± 0.31 6.02 (590)	5.89 ± 0.31 5.79 (782)	6.06 ± 0.37 5.91 (232)	6.13 ± 0.37 5.98 (345)
II A	6.11 ± 0.30 6.01 (295)	6.13 ± 0.29 6.03 (467)	5.91 ± 0.36 5.77 (80)	6.12 ± 0.41 5.94 (112)	6.29 ± 0.34 6.16 (672)
III A	6.13 ± 0.32 6.01 (366)	6.15 ± 0.29 6.04 (114)	6.02 ± 0.18 6.00 (2)	6.07 ± 0.42 5.88 (22)	6.33 ± 0.35 6.18 (382)
I B	6.23 ± 0.29 6.13 (341)	6.16 ± 0.28 6.07 (81)	6.09 ± 0.30 5.98 (297)	6.29 ± 0.36 6.13 (69)	6.50 ± 0.27 6.41 (280)
II B	6.27 ± 0.27 6.17 (166)	6.29 ± 0.24 6.22 (140)	6.27 ± 0.38 6.07 (9)	6.21 ± 0.36 6.07 (44)	6.53 ± 0.26 6.45 (215)
I C	6.23 ± 0.29 6.13 (22)	6.21 ± 0.19 6.18 (7)	6.16 ± 0.30 6.07 (25)		

Table 4. Comparison between pH_1 in LT and SM in plants IV and VI.*

Plant		IV	VI
Number of observations		1697	2002
Mean ± SD pH_1 (measured)	LT SM	5.90 ± 0.30 6.10 ± 0.32	6.30 ± 0.36 6.33 ± 0.36
Mean pH_1 after H+ transformation	LT SM	5.80 5.98	6.15 6.18
r pH_1 LT - pH_1 SM		0.595	0.734
r pH_1 - lean content	LT SM	−0.263 −0.272	−0.179 −0.169
r pH_1 - conformation score	LT SM	0.419 0.401	
r pH_1 - carcass quality index	LT SM	−0.270 −0.236	−0.329 −0.310

* All correlation coefficients mentioned in the table are highly significant

LT and vice versa at the individual animal level. At the animal group level, however, the correlation between mean pH_1 values in LT and SM was much better, i.e. 0.759 and 0.842 in plant IV and VI, respectively. Correlations between pH_1 and lean content, conformation score and visual CQI were all very similar for LT and SM within each plant. Correlation coefficients between H^+ ion concentrations and lean content, conformation score or CQI (not shown) are almost equal or somewhat lower compared to those of pH_1 values with these carcass quality traits (shown in Table 2 and 4).

Discussion

Relatively low mean pH_1 LT values and large proportions of PSE or PSE-prone carcasses were observed in some of the slaughterhouses visited. Although much higher mean pH_1 LT values are generally reported in most studies (see e.g. Bendall & Swatland, 1988), the high proportion of aberrant meat quality encountered in this study is not surprising in view of the good carcass quality. In an extensive survey in six abattoirs, Matzke et al. (1991) found even lower mean pH_1 LT values. The longissimus muscle is often considered as the reference muscle for allocating carcasses to meat quality categories. However, it should be mentioned that variability in pH values and PSE frequencies may occur along the longissimus muscle. Results in the literature on variation in meat quality along the longissimus muscle are not consistent (e.g. Lundström and Malmfors, 1985; Matzke and Holzer, 1989), so this needs more research. Anyway, differences between studies in the site of measurement along the longissimus muscle may partly contribute to differences in the frequencies of PSE-meat reported. It should also be emphasized that presenting means of pH values is influenced by the method of calculation. Enfält et al. (1993) also found that means calculated from measured pH values were higher than those calculated after transformation to hydrogen ion concentration. In addition, the difference seems to be influenced by the variation, as shown in Figure 1 for means calculated for animal groups. Hence, transformation to hydrogen ion concentration before calculating mean values deserves more attention, e.g. in an evaluation system that classifies farmers or suppliers according to mean pH_1 values of animal groups. People do not generally use hydrogen ion concentrations since these are not normally distributed. Logarithmic transformation (pH values) is then necessary to perform statistical tests. However, arithmetic means may be better calculated on the hydrogen ion concentrations.

Large discrepancies in meat quality and carcass quality were seen between slaughtering plants in our study. Differences in mean pH_1 between abattoirs were also reported by Chadwick & Kempster (1983) and Matzke et al. (1991). Kauffman et al. (1992) found large differences in the percentage of visually scored PSE carcasses in fourteen plants. Direct comparison of mean pH_1 values between plants is difficult in our study, since T_{pH} was not standardized. It was found in our laboratory that mean pH_1 decreased by approximately 0.15 units between 30 and 45 minutes postmortem ($n = 38$, data not shown). Hence, mean pH_1 values in plants IV and VI are probably somewhat underestimated and the proportion of PSE carcasses somewhat overestimated compared to the other plants. Somewhat longer waiting times in plant I compared to the other plants may have favoured mean pH_1 values (Warriss, 1987; Matzke et al., 1991; Sackmann et al., 1989). On the other hand, a relatively longer time interval between stunning and sticking was practised in this plant, which is thought to have a negative influence on the rate of pH fall (Ring & Kortmann, 1988). Bleeding out in a hanging position in plants I and VI compared to a lying position in the other plants is sometimes reported to yield lower pH_1 values. In the case of bleeding in a hanging position, Fisher & Augustini (1981) and Matzke et al. (1992) found lower pH_1 values in the ham but not in the loin of the shackled side, whilst Woltersdorf & Troeger (1987) and Rösener & Brenner (1989) found significantly lower values in the loin too. In addition, it was observed that driving the animals to the stunning place was clearly done in a less stressful way in the plants characterised by the lowest rates of slaughtering. Stress imposed upon the animals during the last minutes preslaughter is may be one of the most important environmental factors contributing to accelerated postmortem pH fall. Although no objective information is available on the effect of slaughtering speed on meat quality, Chadwick & Kempster (1983) and Warriss (1987) suggested that the change into larger production and slaughtering units, causing poorer handling of the live animal preslaughter, may be partly responsible for an increased incidence of PSE. Anyway, in our study it is not possible to separate all environmental factors and their effect on pH_1 values, but it is likely that they do partly contribute to the differences observed.

An inverse relationship between meat quality and carcass quality was apparent in our study. Differences in mean pH_1 values between plants could be partly explained by differences in carcass quality. In addition, significant correlations were found beween carcass quality parameters and pH_1 within all abattoirs. Sellier (1988) stated that the antagonism between lean muscle development and PSE incidence mainly depends on the halothane sensitivity status of the population under consideration. Hence, in a study on Dutch slaughter pigs, essentially stress-resistant, De Vries et al. (1992) found that correlations between several meat quality traits and carcass lean content were almost zero. However, in another Dutch study Hovenier et al. (1992) concluded that genetic correlations of backfat thickness and lean content with meat quality traits were unfavourable. Similarly, Sönnichsen et al. (1984), Cole et al. (1988) and Oliver et al. (1991) reported significant negative correlations between meat quality and carcass quality traits in Pietrain and Belgian Landrace populations. Matzke & Holzer (1989) showed a steady increase in bad meat quality with an increase in lean content. In line with Sellier (1988), De Smet et al. (1993) showed that the relationship was stronger for halothane-positive animals than for halothane-negative ones. Although no exact information is available on the origin of the animals in this study, it is known that the stress sensitivity gene is still widely spread in our country. Since this major gene has a particular influence on the shape of the carcass (shorter, more blocked carcasses), it is not surprising that relations of pH_1 with conformation score were even stronger than with lean content. Sather et al. (1981) tried to explain divergency in the quantity-quality relationships between authors by making a distinction in the effects of lean content per se and shape of the musculature. They suggested that an increase in lean content per se need not have an adverse effect on pork quality, whilst the latter may be reduced if improved lean content is accompanied by changes in shape of the musculature. Since the desirable conformation may be achieved easier by the use of stress-sensitive breeds or lines, type Piétrain, the hypothesis of Sather et al. (1981) refers in fact to the influence of halothane sensitivity on the relationship between meat and carcass quality. Anyway, it is clear from the foregoing that further selection for improved lean content will cause further deterioration in meat quality, as long as no meat quality traits are incorporated into selection programmes and as long as much emphasis is put on carcass conformation in view of local market demands.

The very large difference in mean pH_1 between plant IV and VI and the magnitude of the differences in mean pH_1 values between different carcass quality classes strongly suggest that in this field study variability in carcass quality and lean content was a greater source of variability in pH_1 values than environmental factors, as was also conluded by Matzke et al. (1991) in an extensive pH_1 survey. Slaughterhouse IV and VI were quite different in the genetic origin of the animals, but rather similar in the way animals were slaughtered : similar way of stunning, sticking and hanging up, similar mean waiting time before slaughter. Nevertheless, a mean difference of 0.4 pH units was recorded. The maximum difference in mean pH_1 values between carcass quality classes within plants varied around 0.5 pH units and was clearly higher than differences between plants within a certain carcass quality class. In addition, some information (data not shown) on the effect of waiting time before slaughter (one of the environmental factors) shows much smaller differences in pH_1 values than those found for different carcass quality classes. If environmental factors would be more important than genetic factors in meat quality, it may be argued that the antagonistic relationship between carcass and meat quality would not be observable anymore in a field study due to the variety of environmental factors interfering. Hence, although no relationships were established between pH_1 values and non-genetic factors, it is very likely that in this study genetic factors were the main source of variability in meat quality.

Small but significant positive correlations were seen between pH_1 values and warm carcass weight in this study. Whereas lean content and other carcass quality traits are mostly related to carcass weight, this may or may not be the case for meat quality traits (Matzke et al., 1991; Wolf-Schwerin & Kallweit, 1991; Bidanel et al., 1993). Sather et al. (1991) found no relation between pH_1 values and carcass weight, but in pigs heterozygous at the halothane locus some other meat quality parameters seemed to depend on the carcass weight. Hence, it may be desirable in some cases to take account of carcass weight in the evaluation of meat quality traits.

Concerning the choice of muscle for pH measurement, Warner et al. (1993) stated that LT could serve as a reliable indicator of the PSE condition for the major ham muscles. However, the difference in mean pH_1 value between LT and SM seemed to depend on the slaughterhouse in our study. In addition, correlations between both sites in two plants were not very high in order to be used for predictive purposes. In spite of the use of a different pH-meter in LT and SM in plant VI, the correlation coefficient between both measurements was better in this plant than in plant IV. Hence, it seems that the difference was more related to the type of animals slaughtered.

Similar or somewhat higher correlations between LT and SM pH_1 values are generally reported in the literature (Scheper, 1973; Blendl & Puff, 1978; Van der Wal et al., 1987; Oliver et al., 1991). Absolute values of pH_1 means in SM are sometimes close to means in LT but may also be substantially higher (Scheper, 1973; Blendl & Puff, 1978; Van der Wal et al., 1987; Gueblez et al., 1990; Oliver et al., 1991; Wolf-Schwerin & Kallweit, 1991). Certainly, variation in meat quality along the longissimus muscle may be partly responsible for this divergency (Lundström & Malmfors, 1985; Aalhus et al., 1991). It is therefore not clear whether SM and LT values may be interchanged easily. Although both muscles are considered white, high-glycolytic and hence susceptible to the PSE condition, allocating records from both measuring sites to quality groups based on fixed limits (e.g. PSE when $pH_1 < 5.6$) may yield a very different outcome. Ranking of animal groups originating from different farms according to the mean pH_1 in LT or SM may also give somewhat different results, although correlations between mean values at the level of animal groups are higher compared to the individual animal level. Hence, care should be taken when using LT values in order to predict meat quality of the whole carcass or even meat quality of metabolically similar muscles.

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