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Influence of lairage on blood composition of pig and on the development of PSE pork

MARKKU HONKAVAARA

Finnish Meat Research Centre, Box 56,
SF-13101 Hämeenlinna, Finland

Abstract. The purpose of this study was to investigate the effect of lairage temperature, humidity and time on blood composition and on the development of PSE meat ($pH_1 \leq 5.8$).

The present study suggested that holding temperature and time had a major influence on porcine stress and meat quality, whereas, lairage humidity had a minor effect on these traits. The higher was lairage temperature the higher carcass temperature ($P < 0.001$) and log creatine kinase (CK) value ($P < 0.05$) at slaughter. Prolonged holding time increased muscle glycogen content ($P < 0.01$) and muscle pH_1 value ($P < 0.05$) but decreased muscle lactate content in pigs slaughtered on transport day.

In summary, the results suggested that the optimum lairage temperature, humidity and time were respectively 15—18°C, 59—65 % and 3—5 h. These resulted in a low muscle lactate content and PSE frequency, whereas muscle glycogen level was high and pH_1 in *longissimus dorsi* (LD) muscle was in the range of 5.9—6.4 which was acceptable for commercial use.

Index words: abattoir, lairage, blood composition, creatine kinase, PSE meat

Introduction

During lairage, pigs are exposed to a strange and fluctuating environment which might be stressful for them. Therefore, meat quality could be improved by minimizing these fluctuations and by proper handling of animals.

Pigs held in fluctuating temperatures (21—32°C) or in conditions of 37°C and 100 % relative humidity (RH) yielded carcasses with a more rapid *postmortem* (p.m.) glycolytic rate than did pigs reared at a constant 27°C in a moderate 38—42 % RH (CASSENS *et al.*, 1975). At the abattoir, even a moderate and short physical stress influenced plasma lactate, glucose and pH values (KOLCZAK and KRAELING, 1986; LANNEK, 1976; van der WAL, *et al.*, 1985).

DZAPO *et al.* (1981) found that the combined effect of blood CK value and rectal temperature accounted for meat quality defects. Moreover, blood CK activity was significant-

ly correlated with muscle pH and U.S.D.A marbling score (Addis *et al.*, 1974). Furthermore, a high carcass temperature was closely related to a rapid pH fall and the onset of *rigor* which developed PSE meat (Sybesma and van Logtestijn, 1966; Woltersdorf and Troeger, 1987).

Earlier papers (Honkavaara, 1988 and 1989) considered the effect of porcine stress on blood composition and early p.m. meat quality in pigs of different halothane genotypes, and the influence of selection phase, fasting and transport on porcine stress and on the occurrence of PSE. The purpose of this study was to evaluate the effect of lairage temperature, humidity and time on blood composition and on the development of PSE meat.

Material and methods

Treatment during lairage

This study was conducted for nine months from September 1985 to May 1986 by collecting 11—12 pigs per month. The collection of test animals and their treatment programme are described earlier (Honkavaara, 1988). Thus six, six and ten treatments were carried out at the abattoir in Nurmo, Forssa and Salo, respectively. Each treatment consisted of four to eight pigs from one producer. Consequently, 28, 24 and 50 pigs were slaughtered at the abattoir in Nurmo, Forssa and Salo, respectively.

During unloading, blood drops from the ear vein of test pigs were collected on filter paper test cards (Honkavaara, 1988). During lairage, the test animals were held in one box, separated from the rest of pigs. Finally they were slaughtered with the other animals of the same producer.

The temperature and humidity of lairage were measured with a portable hygrometer (Humicap HMI 31, Vaisala, Finland). Lairage duration was the time (min) elapsed between unloading and stunning.

Evaluation of porcine stress and meat quality

Methods used for the evaluation of porcine stress and meat quality are described earlier (Honkavaara, 1988).

Variables

The following 16 "lairage variables" were collected: external temperature (ET), duration of lairage (DL), temperature of lairage (TL), humidity of lairage (HL), fast duration (FD), carcass temperature 0 min *postmortem* (p.m., CT_0), blood creatine kinase (CK) activity during unloading (CKU), CK activity at exsanguination (CKE), serum glucose (SG), serum glycerol (SGL), serum lactate (SL), serum pH (SpH), muscle glycogen 0 min p.m. (MG_0), muscle lactate 0 min p.m. (ML_0), pH in *M. longissimus dorsi* 45 min p.m. (pH_1), carcass hot weight (CW). Moreover, it was calculated the CK change ($100 \times$ (CKE-CKU)/CKU) during lairage. The CKU and CKE values were $\log_{10}$ transformed.

Statistical analyses

Conventional statistical methods were used to calculate means, standard deviations and standard error of the means (SEM). The relations between the measured "lairage variables" and porcine stress and meat quality were analysed by simple regression. Moreover, to estimate the influence of lairage on blood CK activity and carcass temperature, a stepwise linear regression analysis was performed (statistical program PATO for microcomputers, Mikrovuo, Finland).

The regression model (1) included the dependent variable Y_i ($i = 1-3$), the 16 independent variables X_j ($j = 1-16$, $j \neq i$) and the standardized regression coefficients Bj ($j = 1-16$, $j \neq i$).

$$Y_i = B_1X_1 + B_2X_2 + B_3X_3 + \ldots + B_{16}X_{16} \qquad (1)$$

Prediction equations (2) were developed

using stepwise regression analysis (HONKAVAARA, 1989).

$$Y_i = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n \quad (i = 1-3,\ n = 3-5) \qquad (2)$$

Results

Prediction of porcine stress

Table 1 shows the combined effects of studied variables on blood CK activity and carcass temperature during lairage. Thus the coefficient of determination ($R^2 \times 100$) of the prediction equations were for the CK change, CK at exsanguination and carcass temperature 87.0 %, 80.5 % and 71.8 %, respectively. The combined effects of the independent variables of the prediction equations are discussed below.

Lairage temperature

In general, temperature of lairage, TL was positively related to external temperature, ET ($TL = 15.844 + 0.548ET$, $R^2\ 100 = 20$ %, $p < 0.001$). Thus, a 1°C increase in external temperature increased lairage temperature by 0.6°C. In this study, duration of lairage, DL ($DL = 1495.69 - 67.419TL$, $R^2\ 100 = 19$ %, $P < 0.001$) and fast duration, FD ($FD = 1583.82 - 28.224TL$, $R^2\ 100 = 7$ %, $P < 0.01$) were reduced by 67 min and 28 min for each degree increase in lairage temperature, respectively. Moreover, carcass hot weight, CW was positively related to lairage temperature ($CW = 57.322 + 1.148TL$, $R^2\ 100 = 17$ %, $P < 0.001$) which shows that heavy pigs were slaughtered in warm weather.

Furthermore, a 1°C increase in lairage temperature decreased serum lactate, SL by 0.4 mmol/l ($SL = 20.022 - 0.422TL$, $R^2\ 100 = 6$ %, $P < 0.02$) and increased serum pH, SpH by 0.2 pH units ($SpH = 7.615 + 0.024TL$, $R^2\ 100 = 6$ %, $P < 0.02$). In addition, increases in external temperature accounted for 60.0 % of the increase in carcass temperature which, on the other hand, accounted for 14.2 % of the elevation in CK activity during lairage (Table 1). Thus it was concluded that high external and lairage temperature had a detrimental effect on carcass temperature.

The collected data were classified into four groups of nearly the same number of pigs according to the increase in lairage temperature. Table 2 shows the variables that differed significantly between the groups.

At the abattoir, the increase in CK activity was highest at 16°C, whereas this increase was only 82.0 % without reactors. Heat stress elevated blood CK level both during transport and lairage which resulted in a low increase in CK activity in the pigs held at 21°C. In this group, the prolonged heat stress accounted for the smallest muscle glycogen content and the

Table 1. The best stepwise regression models[a] for predicting porcine stress during lairage.

Prediction equations[b]	$R^2\ 100$[c] %	Df[d]
Carcass temperature = $38.609 + 0.801ET - 0.178HL + 0.187MG_0 + 0.259CK\ change$	71.8	4/45
CK at exsanguination = $194.36 + 0.514CKU - 0.092SL + 0.756CK\ change$	80.5	3/87
CK change[e] = $-1000.33 + 0.139CT_0 - 0.677CKU + 1.016CKE + 0.15SL - 0.151MG_0$	87.0	5/44

[a] Regression models have significant F-values ($P < 0.002$).
[b] Abbreviations given in text.
[c] Coefficient of determination × 100.
[d] Degrees of freedom.
[e] CK change (%) $= 100 \times \frac{\text{CK at exsanguination} - \text{CK during unloading}}{\text{CK during unloading}}$.

lowest incidence of PSE. Actually, carcasses of these animals had the slowest pH fall in the LD muscle (Table 2). On the other hand, the occurrence of PSE was highest at 16°C, but it decreased to 8.3 % without reactors. The high PSE frequency at 12°C might result from the stressful treatment when pigs were woken up after overnight holding and were driven to stunning.

Lairage humidity

Humidity of lairage, HL was positively related to external temperature, ET (HL = 51.945 + 2.907ET, R^2 100 = 12 %, $P < 0.002$). Thus, a 1°C increase in external temperature increased lairage humidity by 2.9 %RH. Furthermore, muscle glycogen content, MG_0 was decreased by 0.22 µmol/g for each per cent RH increase in lairage humidity (MG_0 = 41.099 − 0.222HL, R^2 100 = 5 %, $P < 0.03$). However, carcass temperature was poorly described by lairage humidity, as indicated by a low partial R^2 100 of 4.8 % (Table 1).

The collected data were classified into four groups of nearly the same number of pigs ac-

Table 2. Effect of lairage temperature on blood composition and carcass traits.

Variable	Lairage temperature, °C				SEM
	13	16	18	21	
Lairage time, h	13.9[a]	4.4[b]	4.3[b]	2.5[b]	0.75
Fasting time, h	21.8[a]	17.7[b]	17.9[b]	18.5[b]	0.52
CK change[d], %	+89.0	+103.0	+75.9	+61.7	21.9
Serum glucose, mmol/l	6.7[a]	5.0	6.1	4.4[b]	0.05
SErum lactate, »	15.5[a]	11.1[b]	13.3	12.2[b]	0.06
Serum pH	7.9[a]	8.0[a]	7.9[a]	8.3[b]	0.03
Carcass temperature, °C	38.9[a]	38.1[b]	38.8[a,c]	39.6[c]	0.13
Carcass hot weight, kg	69.4[a]	76.5[b]	79.5[b]	79.6[b]	0.79
$pH_1 \leq 5.8$, PSE, %	20.8	21.4	15.8	13.3	—
$5.8 < pH_1 \leq 6.4$, »	66.7	46.4	47.4	26.7	—
$6.4 < pH_1$, »	12.5	32.2	36.8	60.0	—
Reactors, %	0	14.3	3.2	0	—
Number of pigs	24	28	31	15	—

[a,b,c] Means within a row with different superscripts are significantly different ($P < 0.05$).
[d] CK change as in table 1.

Table 3. Effect of lairage humidity on blood composition and carcass traits.

Variable	Lairage humidity, %RH				SEM
	38	49	59	70	
CK change[a], %	+33.1	+149.5	+89.5	+62.3	21.9
Serum glycerol, mmol/l	0.54	0.43[b]	0.76[c]	0.54	0.003
Carcass temperature, °C	39.1[b]	38.8	38.2[c]	38.3[c]	0.13
Glycogen of LD, µmol/g	33.3[b]	29.0	25.3[c]	30.2[b]	0.20
Lactate of LD, »	44.4	50.0[b]	45.6	40.0[c]	0.11
$pH_1 \leq 5.8$, PSE, %	10.5	20.8	29.0	4.2	—
$5.8 < pH_1 \leq 6.4$, »	42.1	54.2	45.2	58.3	—
$6.4 < pH_1$, »	47.4	25.0	25.8	37.5	—
Reactors, %	0	0	18.8	0	—
Number of pigs	19	24	32	24	—

[a] CK change as in table 1.
[b,c] Means within a row with different superscripts are significantly different ($P < 0.05$).

cording to the increase in lairage humidity. Table 3 shows the variables that differed significantly between the groups. Thus, differences between the groups were not significant for holding and fasting time. Whereas the occurrence of reactors accounted for the high CK values and the highest frequency of PSE in the group of 59 %RH. Without reactors, the incidence of PSE decreased from 29.0 % to 15.4 %. Moreover, the group of the highest humidity of 70 %RH had the lowest CK values during unloading ($P<0.05$) and at exsanguination ($P>0.05$). While the pigs of the lowest humidity of 38 %RH had the slowest pH fall in the LD muscle 45 min p.m., however, these animals had the highest carcass temperature at slaughter.

Lairage time

In practice, pigs are slaughtered either on the transport day or after overnight holding. In order to compare the effect of lairage time on porcine stress and meat quality the material was divided into the two groups shown in Table 4. Thus the pigs of the first group, holding time of 2.4 ± 0.9 h, were fed either in the afternoon and were transported in the next morning, or were fed in the morning and were transported in the middle of the day, in any case they were slaughtered on the transport day. Whereas the pigs of the second group, holding time of 19.0 ± 2.0 h, were fed at noon of the transport day, and were held overnight at the abattoir before slaughtering. Consequently the difference in fasting time was significant ($P<0.001$) between the two groups. In addition, pigs of the short and long holding times were slaughtered, respectively, in the afternoon and in the morning which accounted for the difference in lairage temperature.

In general, serum lactate level, SL was positively related to the duration of lairage, DL ($SL = 11.963 + 0.003DL$, R^2 100 = 8 %, $P<0.005$). Thus a 60 min increase in holding time increased serum lactate by 0.18 mmol/l. Nevertheless muscle pH_1 was negatively correlated ($P<0.01$) with the lairage times of 0.5 h to 22 h, there were differences in this

Table 4. Effect of lairage time on blood composition and carcass traits.

Variable	Slaughtering		Sign. level[a]	SEM
	On transport day	After overnight lairage		
Fasting time, h	16.7	24.8	***	0.52
Lairage temperature, °C	17.1	14.4	***	0.28
Lairage humidity, %	55.1	55.3	ns	1.18
Log CK during unloading, U/l	3.5	3.3	ns	0.35
Log CK at exsanguination, U/l	3.5	3.6	ns	0.36
Serum glucose, mmol/l	5.0	6.7	**	0.05
Serum glycerol, »	0.65	0.54	ns	0.003
Serum lactate, »	12.2	15.6	**	0.06
Serum pH	8.0	8.0	ns	0.03
Carcass temperature, °C	38.4	39.3	**	0.13
Glycogen of LD, µmol/g	30.2	22.8	**	0.20
Lactate of LD, »	44.4	47.8	ns	0.13
Carcass hot weight, kg	78.2	70.7	***	0.79
$pH_1 \leq 5.8$, PSE, %	14.9	25.0	—	—
$5.8 < pH_1 \leq 6.4$, »	44.6	67.9	—	—
$6.4 < pH_1$, »	40.5	7.1	—	—
Reactors, %	6.8	3.6	—	—
Number of pigs	74	28	—	—

[a] Significance level: ns = not significant, $P<0.01$**, $P<0.001$***.

relation between the short and long holding times. Actually, in pigs slaughtered on the transport day, a 60 min prolongation of lairage time increased muscle pH_1 value by 0.10 pH units ($pH_1 = 6.042 + 0.002DL$, R^2 100 = 6 %, $P < 0.05$). Whereas a 60 min prolongation of holding time decreased muscle pH_1 value by 0.05 pH units in the pigs slaughtered after overnight lairage ($pH_1 = 7.019 - 0.001DL$, R^2 100 = 11 %, $P = 0.08$).

The difference in pH_1 values between the pig groups results from decreased muscle lactate content ($P < 0.05$) during holding times of 0.5 to 5.0 h, and from increased muscle lactate level ($P < 0.01$) during lairage times of 16 to 22 h. Moreover, the pigs slaughtered on the transport day had smaller serum glucose ($P < 0.01$) and lactate content ($P < 0.01$), lower carcass temperature ($P < 0.01$) and higher muscle glycogen content ($P < 0.01$) than did those slaughtered after overnight holding. In addition, the latter group had lower carcass hot weight ($P < 0.001$) and higher occurrence of PSE than the former group (Table 4).

The combined effects of fast time, lairage temperature and carcass hot weight on studied variables were evaluated by stepwise regression analysis (Honkavaara 1989). Thus, serum lactate was influenced positively but muscle glycogen negatively by fasting time (partial R^2 100 = 17.6 and 8.4 %, respectively). On the other hand, lairage temperature contributed only 5.2 % (partial R^2 100) of the variation in muscle pH_1, whereas carcass hot weight was not a contributing component in the analysis.

The change in CK activity at the abattoir

There were no significant differences in CK activities during unloading or at exsanguination between the three abattoirs. Generally, the change in CK activity from unloading (CKU) to stunning (CKE) was positively related to the CK values at exsanguination (CK change = 12.228 + 0.012CKE, R^2 100 = 44 %, $P < 0.001$), humidity of lairage, HL (CK change = −60.254 + 1.752HL, R^2 100 = 4 %, $P = 0.054$) and carcass temperature, CT_0 ($CT_0 = 38.324 + 0.002$CK change, R^2 100 = 19 %, $P < 0.01$). Thus a 1000 U/l increase in CK activity at slaughter and 10 % units increase in lairage humidity elevated CK change by 12.2 % and 17.5 %, respectively. Moreover, dublication of CK activity at the abattoir increased carcass temperature by 0.2°C. Furthermore, the most contributing variables of CK change were CK at exsanguination

Table 5. Effect of the change in creatine kinase activity at the abattoir on blood composition and carcass traits.

Variable	CK change[a], %			SEM
	−51	+21	+266	
Lairage humidity, %	51.8[b]	56.2	58.3[c]	1.18
Log CK at exsanguination, U/l	3.1[b]	3.6[c]	3.9[d]	0.36
Serum glucose, mmol/l	6.7[b]	5.0[c]	5.0	0.05
Serum pH	7.9[b]	8.1[c]	8.0	0.03
Carcass temperature, °C	37.7[b]	38.6[c]	39.0[c]	0.13
Decrease in muscle glycogen 45 min p.m., %	18.4	16.3	15.6	7.49
Increase in muscle lactate 45 min p.m., %	57.9	32.6	46.2	5.29
$pH_1 \leq 5.8$, PSE, %	19.4	15.2	18.5	—
$5.8 < pH_1 \leq 6.4$, »	45.1	51.5	55.6	—
$6.4 < pH_1$, »	35.5	33.3	25.9	—
Reactors, %	3.2	6.1	3.7	—
Number of pigs	31	33	27	—

[a] CK change as in table 1. The material is classified into three groups according to the increase in CK change during lairage.

[b, c, d] Means within a row with different superscripts are significantly different ($P < 0.05$).

(R^2 100 = 65.8 %) and carcass temperature (14.2 %), whereas CK activity during unloading, muscle glycogen and serum lactate made relatively minor contributions (3.2, 2.1 and 1.7 %, respectively).

The collected data were classified into three groups of nearly the same number of pigs according to the increase in CK activity during lairage. Consequently, the CK change ranged from −82 to 23 %, from −18 to 78 % and from 84 to 969 % in the first, second and third group, respectively. The means of these ranges are shown in Table 5 that lists the variables which differed significantly between the groups.

Thus, the pigs with a decrease of 51 % in CK activity at the abattoir had the lowest CK activity at exsanguination ($P < 0.01$) and carcass temperature ($P < 0.01$). Moreover, these animals had a higher serum glucose level ($P < 0.01$) and a lower serum pH value ($P < 0.05$) than those with a moderate increase (21 %) in CK activity (Table 5). Nevertheless, CK change had no significant correlation with serum glucose, serum pH, muscle glycogen content (0 and 45 min p.m.), muscle lactate level (0 and 45 min p.m.) or muscle pH_1 value. However, the pigs with a decrease in CK activity had the highest occurrence of PSE due to the most prominent p.m. glycogen breakdown and lactate formation.

Discussion

The results showed that the occurrence of halothane positive pigs had a great effect on the studied traits. Since reactors are practically absent from commercially slaughtered pigs they are not reported here in detail.

This study suggested that the optimum lairage temperature was 15—18°C which was lower than that (20—23°C) presented by Webster (1983) to maintain homeothermy with optimal feed conversion efficiency. Combined effect of heat and transport stress caused elevated body temperatures which should be lowered before slaughter, otherwise, according to Sybesma and van Logtestijn (1966) the high carcass temperature could have a prominent effect on the development of PSE. On the other hand, the effect of holding temperature should be evaluated with other factors as lairage time. Thus, it was found that muscle pH_1 correlated positively ($P < 0.05$) with holding temperature, which was supported by our unpublished results from pH_1 measurement in 22 709 pigs.

The influence of lairage humidity on the studied variables was not as significant as that of temperature. However, it was found a negative relation ($P < 0.05$) between humidity and muscle glycogen content.

Lairage temperature and humidity are factors which are difficult and expensive to change in practice. Consequently, it is easier to control holding time than temperature and humidity. In general, the longer lairage time the higher serum lactate level and lower muscle pH_1. Augustini and Fischer (1981) found that overnight holding increased PSE frequency slightly, and according to Moss (1981) blood CK at slaughter was higher after overnight than 2 h lairage. Moreover, Fischer *et al.* (1986) concluded that extended fasting period with abattoir stress did not provide any useful way of alleviating the PSE problem. These findings clearly showed the importance of proper pig handling for minimizing porcine stress at the abattoir.

In summary, the results suggested that the optimum lairage temperature, humidity and time were respectively 15—18°C, 59—65 % and 3—5 h. These resulted in a low muscle lactate level and a low PSE frequency, whereas muscle glycogen content was high and pH in the LD muscle 45 min p.m. was in the range of 5.9—6.4 which was acceptable for commercial use.

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SELOSTUS

Teurastamon navettaolosuhteiden vaikutus sianveren koostumukseen ja PSE-lihan muodostumiseen

Markku Honkavaara

Lihateollisuuden Tutkimuskeskus,
PL 56, 13101 Hämeenlinna

Työssä selvitettiin teurastamonavetan lämpötilan, kosteuden ja sikojen lepoajan vaikutus veren koostumukseen ja PSE-lihan muodostumiseen.

Navetan lämpötilalla ja lepoajalla oli merkittävä vaikutus sikojen stressaantumiseen ja lihan laatuun, sen sijaan kosteuden merkitys oli edellisiä vähäisempi. Mitä lämpimämpää navetassa oli sitä korkeampi ruholämpötila ($P<0.001$) ja veren kreatiinikinaasiaktiivisuus ($P<0.05$). Teurastettaessa siat kuljetuspäivänä lepoajan pidentäminen kohotti lihan glykogeenipitoisuutta ($P<0.01$) ja pH_1-arvoa ($P<0.05$), mutta alensi lihan maitohappotasoa ($P<0.05$). Tulosten mukaan navetoinnin optimiolosuhteet olivat: lämpötila 15—18°C, kosteus 59—65 % ja lepoaika 3—5 h. Näissä olosuhteissa lihan maitohappopitoisuus ja PSE-% olivat alhaiset, lihan glykogeenitaso oli korkea ja pH_1-arvo oli alueella 5.9—6.4, minkä ansiosta liha oli moitteeton jatkojalostukseen.