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Influence of carcass temperature, glycogenolysis and glycolysis 45 min *postmortem* on the development of PSE pork

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Abstract. This study investigated the effect of slaughter stress, scalding and process time from stunning to chilling on carcass temperature, muscle glycogen and lactate content, and the development of PSE meat ($pH_1 \leq 5.8$).

Blood creatine kinase (CK) activity was positively ($P < 0.001$) related to carcass temperature at slaughter. During scalding, carcass temperature raised by $1.2 \pm 1.4°C$, 13 % of muscle glycogen was broken down and lactate level elevated by 5 %. Furthermore carcass temperature fell by $0.7 \pm 0.8°C$, 5 % of muscle glycogen was consumed and lactate content increased by 35 % between scalding and chilling.

The time elapsed from stunning to splitting and further to chilling had a minor effect on carcass temperature, muscle glycogen or lactate content. Whereas, lactate production was positively correlated with the increase in carcass temperature both during scalding ($P < 0.01$) and between stunning and chilling ($P < 0.01$), and with muscle glycogen breakdown ($P < 0.001$). Consequently, the enhanced glycogenolysis during scalding, the accelerated glycolysis between scalding and chilling, and the elevated carcass temperature 45 min *postmortem* (p.m.) resulted in the development of PSE meat.

Index words: slaughter, creatine kinase, *postmortem* glycogenolysis, glycolysis, PSE meat

Introduction

The efforts to imrove pork quality should include the proper handling and management of pigs all along the line from farm to chilling. At the abattoir, the treatments just before slaughtering are easier to control than the p.m. biochemical reactions triggered by stressful handling.

WISMER-PEDERSEN and BRISKEY (1961a) presented four types of p.m. pH falls: a slow gradual, a gradual, a relatively rapid and a sharp, significant decrease. PSE meat resulted when pH_1 (45 min p.m.) was decreased to about 5.4 while tissue temperature remained above 25°C. However, the accelerated chilling rate had no significant effect on final lactic acid content but it did reduce the rate of

lactate formation (WISMER-PEDERSEN and BRISKEY, 1961b).

The heat production and loss from muscles were brought to equilibrium 30 min p.m. (BIERNING-SØRENSEN, 1976). Moreover, the *rigor* and temperature measurements 45 min p.m. gave information about the intensity of treatment before and during slaughtering (SYBESMA and van LOGTESTIJN, 1966). Finally, the rapid pH fall combined with a high carcass temperature developed PSE meat (WOLTERSDORF and TROEGER, 1987).

Earlier papers (HONKAVAARA, 1988, 1989a and 1989b) considered the effect of porcine stress on blood composition and early p.m. meat quality in pigs of different halothane genotypes; the influence of selection phase, fasting and transport on porcine stress and on the development of PSE; and the influence of lairage on blood composition of pig and on the occurrence of PSE.

The purpose of this study was to evaluate the effect of blood CK activity and slaughter line on carcass temperature, muscle lactate and glycogen content, and the development of PSE.

Material and methods

Test animals

38 Finnish Landrace (L) pigs, 8 Finnish Yorkshire (Y) pigs and 56 LxY crosses were slaughtered at three abattoirs. The Central Association of Artificial Insemination Societies determined the halothane genotype of 52 animals, and the results were combined by the Finnish Animal Breeding Association to get the probability for the genotype, the rest were of unknown genotype. The collection and treatment of animals are described earlier (HONKAVAARA, 1989a, 1989b).

Measurements at the abattoir

The temperature and relative humidity were measured with a portable hygrometer (Humicap HMI 31, Vaisala, Finland) in the lairage and on the slaughter line at splitting and before carcass chilling. Moreover, it was measured scalding temperature and time, the time elapsed from stunning to splitting, and from splitting to chilling.

Evaluation of meat quality

Methods used for the evaluation of meat quality are described earlier (HONKAVAARA, 1988). Furthermore, the increase in carcass temperature during scalding and that from stunning to chilling were calculated by subtracting the temperature of 0 min p.m. from that of 10 min p.m. and from that of 45 min p.m., respectively. In addition, the rate of muscle glycogen breakdown and lactate formation were calculated from the samples of *M. longissimus dorsi* (LD) by the formulas:

micromoles (μmol) of glycogen (MG) broken down per 100 g of wet tissue in one minute =

$$\frac{\text{MG 0 min p.m. (μmol/100 g)} - \text{MG 45 min p.m. (μmol/100)}}{\text{time elapsed from exsanguination to chilling (min).}},$$

μmol of lactate (ML) formed per 100 g of wet tissue in one minute =

$$\frac{\text{ML 45 min p.m. (μmol/100 g)} - \text{ML 0 min p.m. (μmol/100 g)}}{\text{time elapsed from exsanguination to chilling (min)}}$$

Variables

The following 34 variables were used in statistical analyses: loading time of day, transport temperature and duration (TD), lairage time, temperature of lairage (TL), humidity of lairage, stunning time of day (ST), fasting duration (FD), scalding temperature (STE) and time (STI), temperature on line at splitting and that before chilling (TEC), humidity on line at splitting and that before chilling, time elapsed from stunning to splitting (TS) and that elapsed from splitting to chilling (TC); blood creatine kinase (CK) activity on farm, during unloading and at exsanguination (CKE); serum glucose (SG), glycerol, lactate and pH; carcass temperature 0 (CT_0), 10 (CT_{10}) and 45 min p.m. (CT_{45}); muscle glyco-

gen 0 (MG_0), 10 (MG_{10}) and 45 min p.m. (MG_{45}); muscle lactate 0 (ML_0), 10 (ML_{10}) and 45 min p.m. (ML_{45}); muscle pH 45 min p.m. (pH_1) and carcass hot weight (CW). The CK 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 variables and meat quality traits were analysed by simple regression. The difference among the means were evaluated by analysis of variance. Moreover, stepwise regression analyses were used to examine the relative predictive value of the measured variables for carcass temperature, muscle glycogen, lactate and pH value 45 min p.m. (statistical program PATO for microcomputers, Mikrovuo, Finland).

The regression model (1) included the dependent variable Y_i ($i = 1—8$) and the 33 independent variables X_j ($j = 1-33$, $j \neq 1$) and the standardized regression coefficients B_j ($j = 1-33$, $j \neq i$).

$$Y_i = B_1X_1 + B_2X_2 + B_3X_3 + \ldots + B_{33}X_{33} \quad (1)$$

Prediction equations (2) were developed using stepwise regression analysis (HONKAVAARA, 1989a).

$$Y_i = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n \quad (2)$$
$$(i = 1—8,\ n = 3—6)$$

Results

Prediction of the development of PSE meat

Table 1 shows the combined effects of studied variables on muscle pH_1 value and on the changes in carcass temperature, muscle glycogen and lactate content 45 min p.m. Thus, the coefficient of determination (R^2 100) of the prediction equations were for the rate of lactate formation and glycogen breakdown, increase in carcass temperature from

Table 1. The best stepwise regression models[a] for predicting biochemical changes in the *M. longissimus dorsi* 45 min *postmortem*.

Prediction equations[b]	R^2 100[c] %	Df[d]
Carcass temperature 45 min p.m. = $6.152 + 0.247TD + 0.209FD + 0.601CT_{10} + 0.217ML_{45} + 0.227CW$	74.2	5/56
Increase in carcass temperature during scalding = $31.892 - 0.603CT_0 + 0.206SG + 0.218SGL - 0.213MG_0$	60.4	4/50
Increase in carcass temperature from stunning to chilling = $11.523 + 0.247FD + 0.37TEC - 0.965CT_0 + 0.569CT_{10} + 0.241ML_{45} + 0.196CW$	84.9	6/48
Muscle glycogen 45 min p.m. = $515.25 - 0.167FD + 0.504MG_{10} + 0.178ML_0 - 0.471ML_{45}$	63.9	4/94
Muscle lactate 45 min p.m. = $9.054 - 0.237TD + 0.349ST - 0.392MG_{45} + 0.377ML_0 - 0.31pH_1$	70.6	5/59
Rate of glycogen breakdown from stunning to chilling = $-6.393 + 0.133STI + 0.948MG_0 - 1.021MG_{45}$	96.1	3/96
Rate of lactate formation from stunning to chilling = $4.493 - 0.112TS - 0.198TC - 0.715ML_0 + 1.063ML_{45}$	96.9	4/86
pH_1 = $11.148 + 3.14TL - 0.325CT_{10} - 0.217ML_{10} - 0.382ML_{45}$	60.2	4/50

[a] Regression models have significant F-values ($P < 0.002$).
[b] Abbreviations given in text.
[c] Coefficient of determination × 100
[d] Degrees of freedom.

stunning to chilling and during scalding, and muscle pH_1 96.9, 96.1, 84.9, 60.4 and 60.2 %, respectively. In addition, the R^2 100 values of prediction equations for carcass temperature, muscle lactate and glycogen 45 min p.m. were respectively 74.2, 70.6 and 63.9 %. The combined effects of the independent variables of the prediction equations are discussed below.

Carcass temperature during scalding

The average increase in carcass temperature during scalding was 1.2 ± 1.4°C. Carcass temperature 0 min p.m. was highly significantly positively correlated with log CK at exsanguination ($r = 0.47$, $P < 0.001$). Moreover, this CK activity contributed 12.9 % of the variation in carcass temperature 0 min p.m. (Honkavaara, 1989a). Figure 1 shows the difference in carcass temperature before and after scalding between the pigs with a low and elevated CK activity. Thus carcass temperatures of 38.5 and 39.6°C at slaughter, X, led to the respective temperature increases of 1.3 and 0.4°C during scalding, Y ($Y = 35.985 - 0.902X$, R^2 100 = 45 %, $P < 0.001$). On the other hand, the higher the blood CK activity at exsanguination, X the smaller was the increase in carcass temperature during scalding, Y ($Y = 3.757 - 0.728 \log X$, R^2 100 = 8 %, $P < 0.05$).

The most contributing components of the increase in carcass temperature during scalding were carcass temperature 0 min p.m., serum glucose and glycerol, and muscle glycogen 0 min p.m. (partial R^2 100 = 45.3, 5.9, 4.9 and 4.3 %, respectively, Table 1). In the present study, neither stunning order nor carcass hot weight had no significant influence on the increase in carcass temperature during scalding.

The lactate content of the LD muscle of the carcasses with the highest CK values were 45.6 µmol/g before scalding and 62.2 µmol/g after scalding. The former value was in the mean range of 45.5 ± 12.2 µmol/g, whereas the latter was significantly ($P < 0.05$) higher than the respective average value of 47.8 µmol/g in this study. So it was suggested that the great occurrence of reactors (20 %) led to a high heat generation due to accelerated glycolysis during scalding in carcasses with the highest CK values (Fig. 1). Furthermore, the effect of halothane genotype on carcass temperature is discussed more accurately earlier (Honkavaara, 1988).

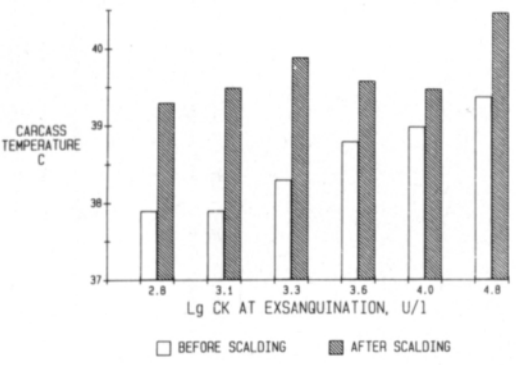

Fig. 1. Effect of CK activity (logarithmic transformation) at exsanguination on carcass temperature.

Carcass temperature from stunning to chilling

The average carcass temperature 0 and 45 min p.m. was 38.6 ± 1.0 and 39.0 ± 1.1°C, respectively. Moreover, the mean increase in carcass temperature during scalding and that from stunning to chilling was respectively 1.2 ± 1.4 and 0.5 ± 1.3°C. Consequently, carcass temperature fell by 0.7 ± 0.8°C between scalding and chilling.

In order to present the influence of carcass temperature on meat quality, the collected data were classified into three groups of nearly the same number of pigs according to the carcass temperature rise between stunning and chilling. Consequently, Table 2 shows the variation in those variables that differed significantly between the groups.

On the slaughter line, the increase in carcass temperature was negatively correlated with the temperature ($r = -0.49$, $P < 0.001$) and humidity ($r = -0.49$, $P < 0.001$) at splitting, temperature ($r = -0.47$, $P < 0.001$) and

Table 2. Effect of carcass temperature on studied variables.

Variable	Change in carcass temperature from stunning to chilling, °C			SEM
	−0.8±0.7	0.3±0.2	2.0±0.7	
Temperature on line at splitting , °C	22.3[a]	21.5[a]	19.7[b]	0.33
Humidity » , %	62.1[a]	60.0[a]	45.5[b]	1.56
Temperature on line before chilling, °C	20.8[a]	19.9	17.7[b]	0.34
Humidity » , %	55.3	58.2[a]	44.5[b]	1.65
Time elapsed from stunning to splitting, min	34.4[a]	31.9[b]	32.4	0.46
Time elapsed from splitting to chilling, min	23.4[a]	23.8[a]	27.3[b]	0.54
Carcass temperature 0 min p.m., °C	39.0[a]	38.8[a]	37.9[b]	0.13
Increase in carcass temperature during scalding, °C	0.2[a]	0.8[b]	2.7[c]	0.20
Rate of glycogen breakdown from stunning to chilling, µmol/(100 g×1 min)	−2.5[a]	1.2	11.1[b]	0.44
Rate of lactate formation from stunning to chilling, µmol/(100 g×min)	17.8[a]	23.3[a]	51.1[b]	0.34
Carcass hot weight, kg	76.9	77.8	76.3	0.79
Prime grading class, E+, %	30.0	50.0	27.8	—
$pH_1 \leq 5{,}8$, %	0	11.1	38.9	—
$5.8 < pH_1 \leq 6.4$, »	45.0	50.0	55.5	—
$6.4 < pH_1$, »	55.0	38.9	5.6	—
Reactors , %	0	0	27.8	—
Number of pigs	20	18	18	—

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

humidity ($r = -0.32$, $P < 0.05$) before chilling, whereas it had a positive correlation with the time elapsed from splitting to chilling ($r = 0.47$, $P < 0.001$). Furthermore, between stunning and chilling, the carcass temperature rise was negatively related to the carcass temperature 0 min p.m. ($r = -0.53$, $P < 0.001$), muscle glycogen content 45 min p.m. ($r = -0.30$, $P < 0.05$) and pH_1 value ($r = -0.58$, $P < 0.001$), while it had a positive relationship with the increase in carcass temperature during scalding ($r = 0.82$, $P < 0.001$), carcass temperature 10 ($r = 0.58$, $P < 0.001$) and 45 min p.m. ($r = 0.67$, $P < 0.001$) and muscle lactate content 45 min p.m. ($r = 0.42$, $P < 0.01$).

The most contributing variables of carcass temperature 45 min p.m. were carcass temperature after scalding (partial R^2 100 = 42.7 %), fast (14.5 %) and transport duration (7.5 %), whereas carcass hot weight and muscle lactate content 45 min p.m. made relatively minor contributions (4.9 and 4.6 %, respectively, Table 1). In addition, the carcass temperature rise from stunning to chilling was determined mainly by carcass temperature after scalding (34.8 %), temperature on line before chilling (20.1 %), carcass temperature at slaughter (11.2 %) and fast duration (10.4 %), and minimally by the muscle lactate content 45 min p.m. (4.8 %) and carcass hot weight (3.6 %, Table 1).

The present results suggested that the degree of metabolic stimulation of muscles at exsanguination determined the temperature of carcass 10 and 45 min p.m. Actually the carcasses with the most prominent temperature rise between stunning and chilling had the highest ($P < 0.001$) increase in temperature during scalding. In contrast, the time elapsed from stunning to splitting and from splitting to chilling had a minor effect on carcass temperature. On the other hand, the temperature rise 45 min p.m. was below the average value of 0.5°C in carcasses with the greatest amount

of prime grading class. Finally, the group that included all reactors had the most prominent increase in temperature 45 min p.m. and the highest PSE frequency (Table 2).

Rate of muscle glycogen breakdown

The average muscle glycogen content 0, 10 and 45 min p.m. was 28.4 ± 12.3, 24.7 ± 12.3 and 23.5 ± 13.6 µmol/g, respectively. This showed the most prominent decrease in glycogen during scalding and a minor decline afterwards. Thus 17.4 % of the glycogen was broken down 45 min p.m. which corresponded to a breakdown rate of 9.9 ± 23.5 µmol/(100 g × min).

Scalding times, X of 6 and 6.5 min resulted in the rates of glycogen breakdown, Y of 1.1 and 4.1 µmol/(100 g × min), respectively ($Y = -106.85 + 17.99X$, R^2 100 = 18 %, $P < 0.001$). Whereas the decline in glycogen content was not significantly related to scalding temperature. Furthermore, on the line, glycogen breakdown was negatively correlated with temperature at splitting ($r = -0.29$, $P < 0.01$), humidity before chilling ($r = -0.25$, $P < 0.05$) and time elapsed from stunning to splitting ($r = -0.34$, $P < 0.01$).

The most contributing components of muscle glycogen content 45 min p.m. were muscle glycogen level after scalding (44.1 %) and muscle lactate content 45 min p.m. (15.3 %), while muscle lactate at slaughter (2.5 %) and fast duration (2.0 %) made relatively minor contributions (Table 1). In addition, the rate of glycogen breakdown from stunning to chilling was determined best by muscle glycogen level 45 (69.0 %) and 0 min p.m. (12.0 %), and scalding time (15.1 %).

The present results suggested that it was difficult to predict meat quality on the basis of muscle glycogen content which, however, will have an important influence on the development of PSE pork through the glycolytic pathway.

Rate of muscle lactate formation

The average muscle lactate content 0, 10 and 45 min p.m. was 45.6 ± 12.2, 47.8 ± 14.4 and 64.4 ± 17.8 µmol/g, respectively. Thus production of lactate was low during scalding, whereas it was greatest afterwards. Consequently, lactate level increased by 41.5 % 45 min p.m. which corresponded to a formation rate of 35.6 ± 30.0 µmol/(100 g × min).

A 0.6 and 1.2°C increase in carcass temperature during scalding, X enhanced lactate production 45 min p.m., Y by 26.0 and 30.5 µmol/(100 g × min), respectively ($Y = 21.533 + 7.511X$, R^2 100 = 13 %, $P < 0.01$). Moreover, carcass temperature elevation from stunning to chilling, X of 0 and 0.5°C resulted in lactate accumulation, Y by 26.7 and 30.9 µmol/(100 g × min), respectively ($Y = 26.744 + 8.378X$, R^2 100 = 15 %, ($P < 0.01$). As a result, muscle lactate content 45 min p.m. was highly correlated with the rate of lactate formation ($r = 0.99$, $P < 0.001$).

Muscle lactate content 45 min p.m. was determined mainly by muscle glycogen 45 min p.m. (36.5 %), lactate 0 min p.m. (13.5 %) and stunning time (11.7 %), and minimally by muscle pH_1 value (7.0 %) and transport duration (1.9 %). In fact, muscle lactate content 45 min p.m. was the single best predictor (83.5 %) of lactate production, whereas the time elapsed from stunning to splitting (6.3 %), muscle lactate level at slaughter (5.2 %) and time elapsed from splitting to chilling (1.9 %) made relatively minor contributions (Table 1). Finally, the most useful predictors of muscle pH_1 were carcass temperature (34.6 %) and muscle lactate (12.1 %) after scalding, muscle lactate 45 min p.m. (8.3 %) and lairage temperature (5.2 %). In summary, it was concluded that muscle lactate content provided a useful predictor of meat quality, especially that of PSE pork.

Discussion

In general, blood CK activity and carcass hot weight correlated negatively with carcass

temperature rise during scalding. Moreover without reactors, carcass temperature fell between stunning and chilling. Whereas in reactors, carcass temperature raised due to accelerated glycolysis during scalding and 45 min p.m. which resulted in the development of PSE. This agreed with SCHNEIDER *et al.* (1980) who found that reactors had the highest CK activity and the lowest pH_1 value. In addition, SYBESMA and van LOGTESTIJN (1966) found that a high carcass temperature was related to a rapid pH fall and the onset of *rigor*.

The rate of glycogenolysis was fastest during scalding after that it reduced up to the chilling. Carcasses with the most prominent rate of glycogen breakdown had the highest muscle glycogen content 0 min p.m. and the greatest PSE frequency. This was consistent with WISMER-PEDERSEN and BRISKEY (1961a) that a muscle with a sharp pH fall of 5.1 at 1.5 h contained more glycogen at slaughter than those with a slower pH fall.

Lactate production was low during scalding but it enhanced from scalding to chilling. Thus it was suggested that, during scalding, a major part of glycogen was broken down to glucose, whereas a minor part of glucose was degraded to yield lactate. After scalding, a major part of glucose was consumed in glycolysis to produce lactic acid. This production was accelerated by elevated carcass temperature. On the other hand, the carcasses with the fastest rate of lactate formation included a great amount of reactors, had the smallest proportion of prime grading class and the highest occurrence of PSE. A similar result was obtained by LAWRIE (1960) that a fast rate of glycolysis was associated with a great degree of exudation.

In summary, the results suggested that to avoid the development of PSE meat the rate of glycogenolysis and glycolysis should be reduced so that the carcass temperature will raise as low as possible during scalding and there will be a total fall in carcass temperature 45 min p.m.

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SELOSTUS

Ruholämpötilan, glykogenolyysin ja glykolyysin vaikutus PSE-lihan muodostumiseen 45 min *postmortem*

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Tutkimuksessa selvitettiin teurastusstressin, kalttauksen ja tainnutuksesta pikajäähdytykseen kuluneen ajan vaikutus ruholämpötilaan, lihaksen glykogeeni- ja maitohappopitoisuuteen sekä PSE-lihan ($pH_1 \leq 5.8$) muodostumiseen.

Mitä suurempi oli veren kreatiinikinaasi- (CK-) aktiivisuus sitä korkeampi ruholämpötila ($P < 0.001$). Kalttauksen aikana ruholämpötila kohosi 1.2 ± 1.4°C, lihaksen glykogeenistä hajosi 13 % ja maitohappopitoisuus kasvoi 5 %. Ruhon kulkiessa kalttauksesta pikajäähdytykseen sen lämpötila aleni 0.7 ± 0.8°C, lihaksen glykogeenipitoisuus väheni 5 % ja maitohappoa muodostui lisää 35 %.

Ruhon kulkuaika pistosta halkaisuun ja siitä pikajäähdytykseen ei vaikuttanut merkittävästi sen lämpötilaan, lihaksen glykogeeni- tai maitohappopitoisuuteen. Sen sijaan maitohapon muodostumista lisäsivät kohonnut ruholämpötila kalttauksessa ($P < 0.01$) ja pistosta pikajäähdytykseen ($P < 0.01$) sekä kiihtynyt glykogeenin hajoaminen ($P < 0.001$). PSE-lihan muodostumisen aiheuttivat glykogenolyysin voimistuminen kalttauksessa, glykolyysin kiihtyminen kalttauksesta pikajäähdytykseen ja korkea ruholämpötila 45 min *postmortem*.