AN ATTEMPT TO RELATE MEAT QUALITY OF PORK (M. LONGISSIMUS DORSI) TO MEAT STRUCTURE

Larsson, G. and Tornberg, E., Swedish Meat Research Institute, POB 504. 8-244 00 Kävlinge, Sweden

SUMMARY

The structural background of meat of different quality (normal, PSE and DFD) was studied for 40 pigs. The techniques used in this study were proton pulse NMR, microscopy and sarcomere length measurement. In order to classify the meat in the three quality groups, ultimate pH, internal reflectance and drip loss were registered.

Three discernible domains of water (relaxation processes) were usually found with the proton pulse NMR. The DFD meat had the shortest relaxation time for the water around the fibre bundles (T22) and the PSE group had the shortest relaxation time for the water inside the fibre bundles (T23).

The variation in sarcomere length was greatest in the PSE group. The widest extracellular channels were also found for the PSE samples.

INTRODUCTION

Good quality pig meat is assessed by a lean meat colour and a minimum in drip loss. Aberrations in these properties are attributed as PSE-meat. Another deviation in meat quality, although not so frequent in pork, arises from meat of enhanced ultimate pH (pH $\geq$ 6.0 in LD, DFD-meat).

PSE muscle is caused by an abnormally rapid fall in pH, while the carcass temperature is still high (Bendall and Wismer-Pedersen 1962). This leads to partial denaturation of some of the meat proteins. DFD muscle is obtained as a consequence of lowered glycogen content just prior to death.

PSE-meat can be identified visually or by measuring the reflectance; the external with reflectometers such as EEL and Göfo and the internal with instruments like the FOP, the HGS and the MQM measuring probes. We have, in this investigation, used the FOP instrument, where FOP-values $\geq$ 55 were considered as PSE.

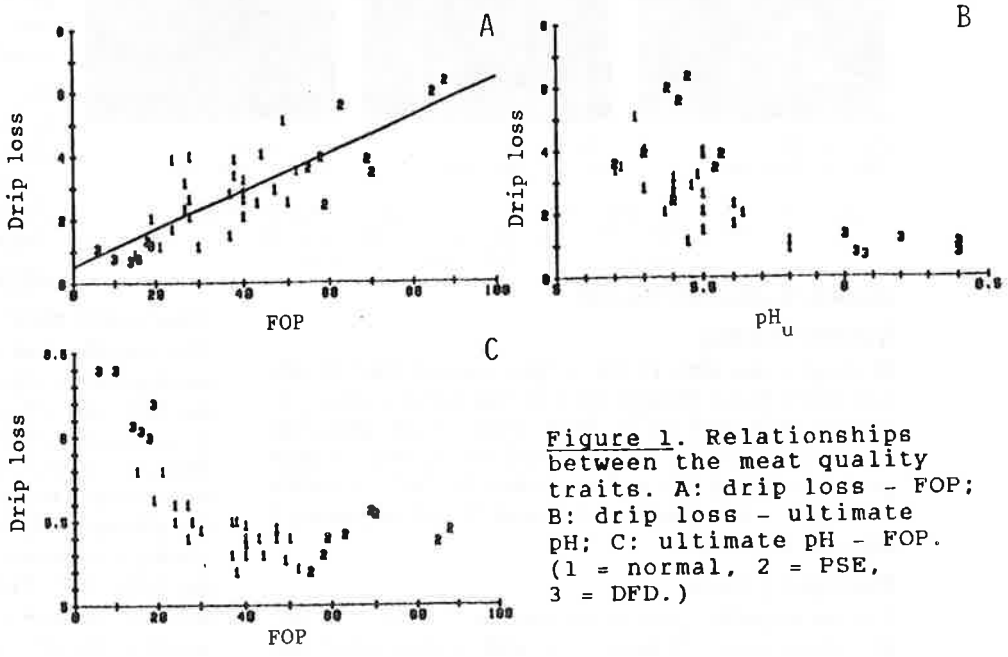
Other widely used indicators of meat quality are the measurements of the initial (pH_1 = pH 1 hour after slaughter) and/or ultimate muscle pH_u. A pH_1 of less than about 6.0 or 5.8 has been associated with PSE meat and a $pH_u \geq 6.0$ with DFD meat. It has only been possible to determine ultimate pH in this study.

The lowered water-holding capacity (WHC) is another property of the PSE-meat which is important to register. In this study, the drip loss according to Lundström et al. (1984) was measured. Studying the water-holding in meat using the non-destructive ^{1}H-pulse-NMR (Nuclear Magnetic Resonance) technique has been proved to be fruitful, as shown, amongst others, by Tornberg and Larsson (1986). Measurements of this type have also been performed in this investigation. A special advantage with the latter method is that the water distribution of the meat is registered, which in turn reflects the structural heterogeneities within the meat. Therefore, it gives information about the micro-structure of the meat, which this article aims to relate to meat quality.

Literature on the meat structural changes of PSE meat is relatively scarce. Honikel and Kim (1986) have followed the protein changes in PSE muscle and found that about 20% of the muscle protein is subject to alteration. Astonishingly, they also observed that no contractions occurred on rigor mortis for PSE muscle. Cloke et al. (1981), however, found PSE muscle far more sensitive to severe contraction than the normal muscles. Literature on this aspect can often be contradictory. We have, in this investigation, followed the state of contraction by measuring the sarcomere length and studied the transverse change in the meat structure by microscopy.

	Normal (N)		PSE		DFD		Significance level		
	x	SD	x	SD	x	SD	N-PSE	N-DFD	PSE-DFD
Meat quality traits	(n = 26)		(n = 8)		(n = 6)				
Ultimate pH	5.45	0.15	5.41	0.12	6.18	0.18		***	***
FOP value	35.1	10.3	68.4	12.3	13.8	5.0	***	***	***
Drip loss (%)	2.7	1.0	4.4	1.4	1.0	0.3	***	***	***

Table 1. Meat quality traits for the three meat quality groups normal, PSE and DFD.



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(Ed. T. Froystein, E. Slinde and N. Standal), Agricultural Food Research Society, Ås, Norway, p205.

Barton-Gade, P. (1987). *In* Evaluation and control of meat quality in pigs, (Ed. P. V. Tarrant, G. Eikelenboom and G. Monin), Martinus Nijhoff Publishers, p117.

Honikel, K. (1987). *In* Evaluation and control of meat quality in pigs, (Ed. P. V. Tarrant, G. Eikelenboom and G. Monin), Martinus Nijhoff Publishers, p273.

Hornsey, H. C. (1956). *J. Sci. Food Agric.* **7**:534.

Jeacocke, R. E. (1984). Proc. 30th European Meeting of Meat Research Workers, Bristol, p104.

Johansson, K. (1987). *Acta Agric. Scand.* **37**:108.

Krzywicki, K. (1979). *Meat Science* **3**:1.

Lundeheim, N., Johansson, K. and Andersson, K. (1980). *Acta Agric. Scand.* **30**:183.

Lundström, K. (1975). *Swedish J. Agric. Res.* **5**:209.

MacDougall, D. B. (1984). *In* Proc. Scient. Meeting Bio-physical PSE-muscle Analysis, (Ed. H. Pfützner), Vienna, p162.

Offer, G. and Trinick, J. (1983). *Meat Science* **8**:245.

SAS Institute Inc., (1985). SAS User's Guide: Statistics. SAS Institute Inc., Cary, NC

Stabursvik, E., Fretheim, H. and Froystein, T. (1984). *J. Sci. Food Agric.* **35**:240.

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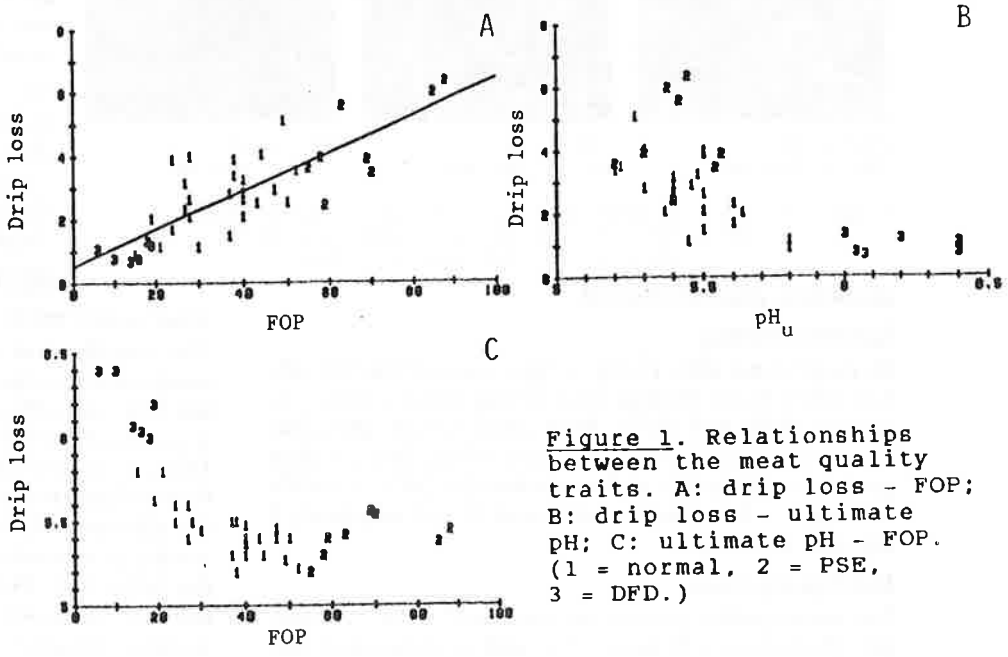

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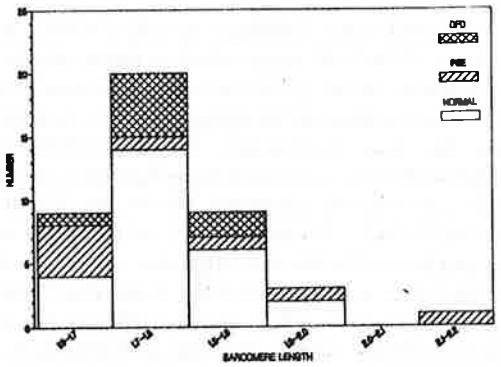


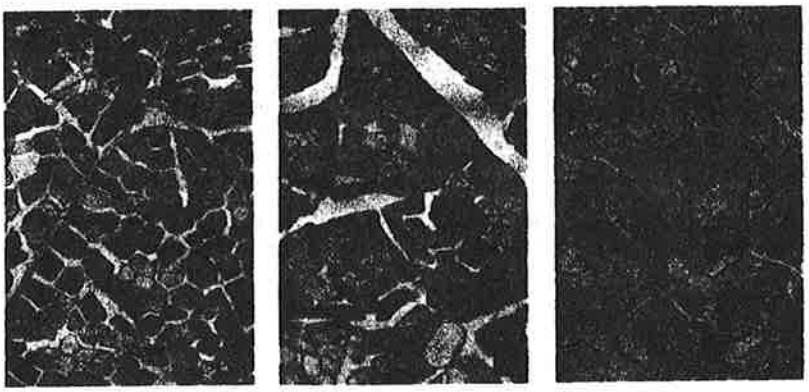
Figure 2. Frequency distribution of the sarcomere lengths for different types of meat quality.

Pulse-NMR data	Normal (N)		PSE		DFD		Significance level		
	x	SD	x	SD	x	SD	N-PSE	N-DFD	PSE-DFD
T22 (ms)	131,9	17,9	145,0	18,0	98,4	14,5	p=0,08	***	***
T23 (ms)	43,9	2,8	40,8[a]	2,9	43,2	3,5	**		
P22 (%)	14,8	5,2	12,2	4,4	16,3	5,6			
P23 (%)	84,7	5,2	87,4	4,4	83,5	5,7			

Significance level $p \leq 0.05$*, $p \leq 0.01$**, $p \leq 0.001$***.

a) The weighted mean value of the two fastest relaxation times is induced in T23 for 3 samples with four relaxation times.

Table 2. Pulse-NMR characteristics - the influence of meat quality.



FOP = 40
T22 = 112 ms

FOP = 88
T22 = 161 ms

FOP = 10
T22 = 102 ms

Figure 3. Photographs of cross sectional cuts from LD muscle with different meat quality (N = normal, P = PSE and D = DFD).

MATERIAL AND METHODS

Sample handling

M. longissimus dorsi (LD), in the region of the last rib, was taken from 40 pigs of differing meat quality i.e. normal, PSE and DFD. Both pure breeds (Swedish Landrace, Swedish Yorkshire and Hampshire) 3 days post mortem (p.m.) and cross-breeds (50% Swedish Landrace + Swedish Yorkshire and 50% Hampshire), 1 day p.m. were used.

Meat quality traits

The meat quality parameters measured were: ultimate pH (Portamess pH-meter 651 with a glass electrode Ingold 404), internal reflectance (FOP, Fibre Optic Probe, TBL, Leeds, England) and drip loss (Lundström et al. 1984).

Meat structure traits

Microscopy: work was performed mainly according to Kotter (1955) described by Tornberg and Larsson (1986).

Sarcomere length: for the sarcomere length measurements a piece 15 x 5 mm Was taken from the centre of a slice of the LD. The piece of muscle was further cut into four smaller parts and fixed according to the procedure used by Cross et al. (1980-81). The lengths of the sarcomere diffraction bands were recorded using a helium-neon laser (Voyle, 1971).

Pulse-NMR measurements: two small rods of fresh meat, approximately 7 mm long and 35 mm^2 in cross sectional area were put into NMR tubes with the fibres perpendicular to the tube wall. The samples were thermostatically held at 25°C for 15 minutes before the NMR measurements.

The water distribution was recorded by a proton-pulse-NMR instrument (Bruker, Minispec, PC/20). The transverse relaxation time (T_2) of the water protons within the meat was recorded at a frequency of 20 MHz at 25°C by using the Carr-Purcell-Meibom-Gill method (Meibom & Gill, 1958). The T_2-recordings were made for τ-spacing 4000 μs and at each measurement 49 scans were accumulated. Data were collected in the time range from 8 up to 1350 ms. The time lapse between two consecutive measurements was 10 s to allow the nuclear magnetisation to return to equilibrium value.

The relaxation data were analysed in multiexponential decay by curve decomposition using a microcomputer (Luxor ABC 806) as described by Tornberg and Nerbrink (1984) and Tornberg and Larsson (1986).

RESULTS AND DISCUSSION

Meat quality traits

The classification of the meat with regard to the three meat quality groups normal, PSE and DFD was based on the FOP and pH values. Pig meat with FOP values ≥ 55 was considered PSE and pigs with ultimate pH ≥ 6.0 as DFD. In the experimental material of 40 pigs altogether, 8 were found to be PSE and 6 DFD. The mean values of the ultimate pH, FOP and drip loss for each of the meat quality groups are given in table 1. As can be seen from the table, both FOP and drip loss differed significantly between the groups, whereas normal and PSE meat had a similar ultimate pH.

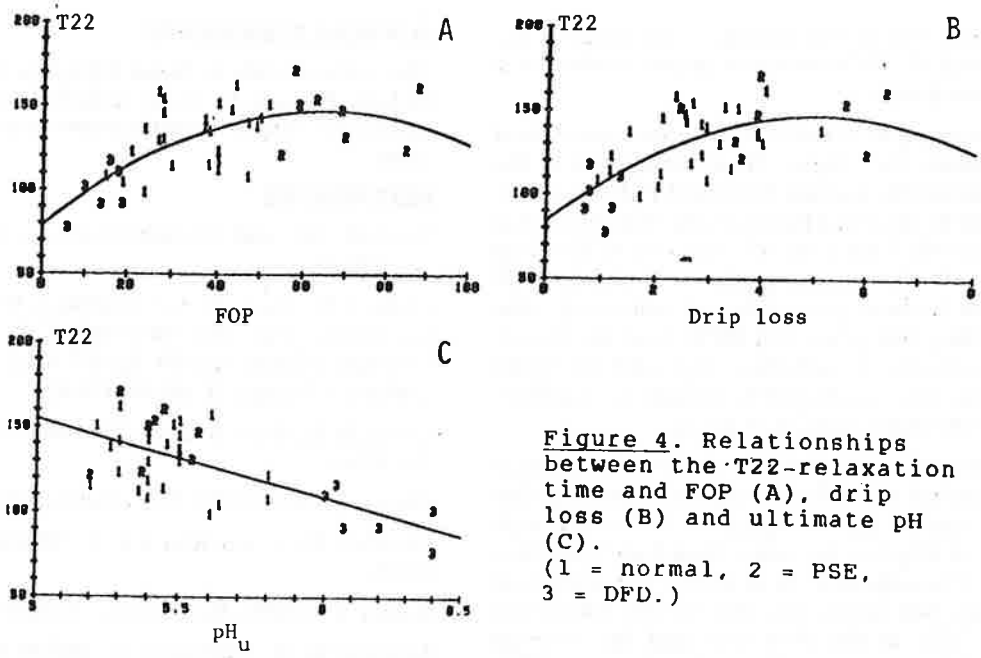


Figure 4. Relationships between the T22-relaxation time and FOP (A), drip loss (B) and ultimate pH (C).
(1 = normal, 2 = PSE, 3 = DFD.)

The relationships of drip loss to FOP and ultimate pH, and of ultimate pH to FOP are presented in figure I.

The plot between drip loss and FOP values (diagram A) can be considered linear ($r = 0.81^{xxx}$). The variation in drip loss for normal and PSE meat of the same FOP value can, however, be as large as 3%. One reason for this might be the method used for drip loss. Drip loss depends, among other things, on the sample size (surface area/height), storage time and storage environment (Honikel, 1987).

It is of further interest to note that the FOP-values are relatively sensitive to pH-changes in the lower region, i.e. at FOP-values ≤ 30 (see diagram C in figure 1). This gives the possibility of differing between DFD and normal meat with the help of internal reflectance measurements. Because, as revealed by diagram B in figure 1, drip loss is relatively independent of pH from approximately 5.6 to 6.4 and cannot therefore be a base for the selection of DFD from normal.

Conclusively, this investigation of relatively restricted material (n = 40) indicates that measurement of the internal reflectance at 900 nm (FOP) is relatively valid in selecting the three meat quality groups normal, DFD and PSE. This is probably due to the fact that these types of measurement are sensitive to both different ultimate pH in the lower region (differentiating DFD from normal) and variation in drip loss in the upper region (differentiating PSE from normal).

Meat structure traits

In figure 2, a histogram of the variation in sarcomere length obtained for the different types of meat quality is given. It can be observed that the PSE meat can have both the longest sarcomeres as well as the shortest, which further substantiates the contradictory results found in the literature. DFD meat does not show the same extent of variation in sarcomere length as the PSE-meat. The former meat quality possesses preferably shorter sarcomere lengths (1.6-1.9 μm). On the whole, the influence of the different types of meat quality on the course of rigor is a little explored area of research, which needs further investigation.

A three-component T2 relaxation behaviour is mostly observed in the 'H-pulse-NMR measurements, which indicates that there are three water regions with populations P21, P22 and P23, that can be quantified. The longest relaxation time considered as 'free Water', has been excluded from the results because it only accounts for 1% of the water.

The results of the pulse-NMR measurements are given in table 2. The major fraction (70-94%) of the muscle water has a relaxation time (T23) between 35-50 ms. The rest of the water relaxes in the range of 70-180 ms (T22).

The PSE group has, on average, the fastest T23 and differs significantly in comparison with the two other meat qualities. The DFD group has the fastest T22 and the PSE group has a tendency to have the slowest T22. In some PSE samples, i.e. 3 out of 8 duplicates, four relaxation processes were found. This indicates more structural inhomogeneities for this type of meat quality.

By assuming that the fast exchange between the small bound fraction of water adjacent to the biopolymers and the larger 'free' fraction of water is the cause of the reduced relaxation time of water protons, a long relaxation time suggests a long diffusion distance of the 'free' water protons to the exchange site. This means that larger pores of water within the structure have a greater chance of obtaining longer relaxation times than smaller pores. We have, in earlier investigations (Tornberg and Larsson, 1986), observed that T22 can be mainly associated with the perimysial water and T23 with the water within the fibre bundles. This distinction between the two domains of water within the meat is not clear-cut, rather fluent, as the water proton relaxation times are dependent on the actual pore size distribution within these domains of water in the meat. For the sake of clarity, we will make this over-simplification and assign the water

relaxation according to T22 mainly to the water at the perimysium and the T23-relaxation mainly to the water within the fibre bundles.

When the micrographs of the transverse sections of meat of varying quality (see figure 3) are compared to the T22-relaxation of the normal, DFD and PSE meat (see table 2), it can be observed that the wider the channel at the perimysium the longer the T22-relaxation. This is in accordance with the reasoning above. Evidently, PSE meat has the highest probability of obtaining wide channels at the perimysium and DFD meat the lowest, which is in accordance with their high and low water holding capacities, respectively (assuming capillary forces reigns the water holding of meat).

However, if the values of 122 for all the investigated meat are plotted against the different measured meat quality traits, which can be seen in figure 4. T22 is relatively independent of drip loss for values from 3 up to 6% (see diagram B). Consequently, meat with FOP-values from 40 to 80 does not either give rise to any substantial increase in T22, as the drip loss and the internal reflectance of the meat are well correlated ($r = 0.81^{xxx}$). The meat quality parameter that mostly influences the T22-relaxation is the ultimate pH, which is revealed by diagram C of figure 4. This suggests that the changes in water pore size distributions due to differences in the ultimate pH are more reflected in T22-relaxation than those variations in the larger water pores more important for the water holding of meat. Evidently, the measurement of the T22-relaxation of water protons could be used to select DFD meat from normal, but it is less accurate in differentiating PSE meat from normal.

ACKNOWLEDGEMENTS

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REFERENCES

Bendall, J.R. and Wismer-Pedersen, J. (1962). *J. Food Sci.* **27**:144.

Cloke, J.D., Davis, E.A., Gordon, J., Hsieh, S.-I., Grider, G., Addis, P.B. and McGrath, C.J. (1981). Scanning electron microscopy/III (p.435-446) SEM Inc. AMF O'Hare (Chicago, IL 60666, USA).

Cross, H.R., West, R.L. and Dutson, T.R. (1980-81) *Meat Sci.* **5**:261.

Honikel, K.O. (1987). *Fleischwirtschaft.* **67**(4).

Honikel, K.O. and Kim Ch.-J. (1985). *Fleischwirtschaft* **65**(9).

Kotter, L. (1955). *Berl. Münch. Tierärtzl. Wschr.* **68**:360.

Lundström, K., Bjärstorp, G. and Malmfors, G. (1984). Proc., Biophysical PSE-muscle Analysis. April, p.26-27. Vienna Technical University, Austria.

Meiboom, S. and Gill, D. (1958). *Rev. Sci. Instrum.* **29**:688.

Tornberg, E. and Larsson, G. (1986). 32nd European Meeting of Meat Research Workers, Ghent, 9:4.

Tornberg, E. and Nerbrink, O. (1984). 30th European Meeting of Meat Research Workers, Bristol, 3-10, 112.

Voyle, C.A. (1971). 17th European Meeting of Meat Research Workers, Bristol. p.95.