CHAPTER 7

PREDICTION OF WATER-HOLDING CAPACITY AND COMPOSITION OF PORCINE MEAT WITH COMPARATIVE SPECTROSCOPY

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ABSTRACT

Spectroscopic measurements using an optical fibre probe (FOP), visual (VIS) and near infrared (NIR) reflectance, fluorescence and low field ^1H nuclear magnetic resonance (LF-NMR) were performed on two muscles (longissimus dorsi and semitendinosous) from 39 pigs, of which 18 pigs were carriers of the Halothane gene. Water-holding capacity (drip loss and filter paper wetness) and chemical composition (intramuscular fat and water) of the muscle samples were determined for spectroscopic calibration. Prediction models between the spectroscopic data and the reference information were established with partial least squares regression (PLSR) to evaluate the potential of using the spectroscopic techniques in an on-line system for meat quality measurements. VIS data resulted in good prediction models indicating that current industrial colour systems can be advanced into more specific meat quality systems by including the entire visual spectral range. LF-NMR data resulted in the best regression models for all reference quality measures and gave a correlation coefficient of 0.75 to drip loss. Based on the characteristic longitudinal relaxation time T_{21}, LF-NMR proved able to distinguish between the two muscle types but not to detect muscles from Halothane positive pigs. The T_{21} separation between the two muscle types was found to be proportional to the difference in average myofibrillar cross-sectional areas.

INTRODUCTION

Instrumental techniques for rapid screening of meat quality (e.g. water-holding capacity and chemical composition) which can be used as a guide for the automation processes in the industry are of great interest for both the industry and the consumers.

The use of rapid spectroscopic techniques for (on-line) meat quality inspection has been successfully demonstrated in a few applications. Jensen *et al.* (1989) used ultraviolet fluorescence for detection of the tissue components of meat. In beef, Swatland *et al.* (1992, 1995a, 1995b, 1997, 1998) has proposed the ultraviolet fluorescence technique for measurement of connective tissue in relation to tenderness, validated with sensory properties, dynamic electromechanical toughness, and needle penetration resistance. Swatland (1995a) used visual reflectance for the determination of water-holding capacity, pH and light reflectance of porcine meat. Borggaard *et al.* (1989) and Andersen *et al.* (1995) studied the relationships between a single near infrared wavelength (950 nm) and water-holding capacity (WHC) and intramuscular fat (IMF) in porcine meat. The NIR study on WHC by Borggaard *et al.* (1989) have recently been extended with fibre optical measurement, using multiple NIR wavelengths by Forrest *et al.* (1997).

The use of low resolution nuclear magnetic resonance in relation to water content and distribution in meat, especially pork muscle, has been reported abundantly in the literature. NMR imaging is widely used for diagnostic purpose in medical applications, and has been used for separation of Halothane positive from normal animals by Decanniere *et al.* (1993). Low resolution NMR, which is relatively and more realistic for rapid on-line/at-line use has been evaluated for use in relation to meat quality in several studies (Renou et al., 1985; Fjelkner-Modig and Tornberg, 1986; Renou et al., 1989; Borisova and Oreshkin, 1992; Tornberg et al., 1993). Trout (1988) promotes the use of NMR for water binding analysis.

Garrido *et al.* (1995) discussed the use of electrical conductivity, pH and light scattering for on-line classification of porcine meat quality extremes. pH proved to be the best discriminator at 45 min post mortem, but none of these techniques were impressive alone. They found, however, that combining pH and light scattering resulted in reasonable classification of the quality groups.

Despite intensive research efforts, no industrial break-through in the on-line instrumental measurements of functional porcine meat quality have yet been devised. Colour vision (BCC-2, SFK Technology, Herlev, Denmark) and the use of the reflectance value from the Fat-O-Meater (FOM; SFK Technology) and the Hennessy probe (Hennessy Europe, EH Rijewijk, NL) from carcass grading measurements seem to be the closest step to on/at-line use of spectroscopy so far.

Hitherto only few comparisons of spectroscopic techniques in relation to meat quality and meat composition has been reported. The aim of this study was therefore to compare the potential of using different spectroscopic techniques for on-line measurements to predict the WHC and chemical composition (water and fat contents) of porcine meat. The spectroscopic techniques selected for this study were an insertion fibre optical probe (FOP), visual (VIS) and near infrared (NIR) reflectance spectroscopy, fluorescence spectroscopy and low field ^{1}H nuclear magnetic resonance (LF-NMR). To attempt to create a large variation in the muscle samples, two conditions were activated. Firstly, stress sensitive and non-stress sensitve animals were used to increase the WHC variation. Secondly, samples were taken from both the loin muscle (M. longissimus dorsi; LD) and the ham muscle (M. semitendinosus; ST) in order to increase the meat composition variation variation.

MATERIAL AND METHODS

EXPERIMENTAL DESIGN AND MEAT SAMPLING

A total of 39 DDLY (Danish Duroc as terminal sire and Danish Landrace × Large White dams) pigs were slaughtered in the Research Centre Foulum at three different weeks. Within litter and slaughter week, 18 of the 39 pigs were free of the Halothane gene (HAL-NN) and 21 of the 39 pigs were heterozygote (carriers) of that gene (HAL-Nn). At 24 h *post mortem* FOP measurements were collected and meat samples of approximately 300 grams were dissected from the loin muscle (M. longissimus dorsi; LD) at the 10'th rib and from one ham muscle (M. semitendinosus; SM). Approximately 50 gram sample from each dissected muscle type were frozen and stored at –20 ^{o}C until measurements of water and IMF contents were performed. Approximately 100 gram from each sample was used for the water-holding capacity determination. At 24 hr *post mortem*, the rest of the fresh meat samples was transported for 4 hr to the spectroscopy laboratory while kept at 8°C. NIR, VIS, fluorescence, and LF-NMR measurements were collected at 48-54 h *post mortem*. LF-NMR was only measured in the two first weeks on samples from 26 pigs, and fluorescence was only measured in the two last weeks on samples from other 26 pigs.

WATER HOLDING CAPACITY AND CHEMICAL ANALYSES

Water holding capacity was measured as 1) drip loss, whereby the loss of water from a 2.5 cm thick slice of muscle taken 24 h *post mortem* was hanging for 2 days in double plastic bags at +4^{o}C is registered (Honikel, 1987), and 2) as filter paper wetness expressed by percentage weight gain (Kaufmann *et al.*, 1986). Fat was determined as Stoldt-Fat (Stoldt, 1952), and water was measured by weighing the sample before and after freeze-drying followed by 4 hr heating at 100 °C.

FIBRE OPTIC INSERTION PROBE

Internal reflectance is measured with a custom designed FOP (Ocean Optics Europe, Top Sensor Systems, Eerbek, NL) optimised for meat use with a sharp tip, thus enabling insertion into the meat through the skin. This approach is a potential on-line sampling system, while the sampling with the other spectroscopic systems used in this study are typical laboratory equipment. The FOP system is constructed with a double channel optical cable, with one channel optimised for the ultraviolet to visual (UV-VIS) range (280-730 nm) and one channel optimised for the visual to near infrared (VIS-NIR) range (500-980 nm). Each channel consist of 7 fibres, 1 for illumination of the meat and 6 for collection of the surface reflectance. Thus a total of 14 fibres exist in the optic cable. Each channel is connected to an illumination source and a spectrophotometer. A total area with a diameter of approximately 5 mm is measured with the probe. The illumination source for the UV source is a combined Deuterium-Halogen lamp (DH-2000) and for the VIS a Halogen-Tungsten lamp (HG-1000). The spectrophotometers for the two channels are combined in a dual line spectrophotometer (PSD-1000) connected externally to a portable PC via a PCMCIA protocol. The spectra are measured at a sampling frequency of 33 kHz by averaging four samples. Using the reference measurement of a $BaSO_4$ solution the raw reflectance measurement is transformed into absorbance units.

NEAR INFRARED AND VISUAL REFLECTANCE

Near infrared and visual reflectance (NIR and VIS) are recorded with a NIR Systems 6500 (Silver Spring, Maryland, USA). The incident light is illuminated on the sample from 180° and reflectance was measured at a 45° angle. The samples were positioned in a sample cup equipped with a quartz window with a diameter of 25mm. A compressible paper-disk were used to force the slice of meat against the quartz window. The measured spectra are separated into the VIS range from 400-800 nm and the NIR range 802-2500 nm.

FLUORESCENCE

Fluorescence data were collected on a Perkin Elmer (Buckinghamshire, UK) LS-50B grating spectrophotometer on a round fragment of the meat positioned in a solid sample holder with a fluorescence-free quartz window. A pulsed xenon lamp excites the sample, and the fluorescence signal is registered with a photomultiplier detector. A scanspeed of 8 nm/min and a slitwidth of 8 nm were used on both excitation and emission. Complete excitation-emission fluorescence landscapes were collected from two meat samples that covered the main variation in the data material. From these fluorescence landscapes four excitation wavelengths: λ_{ex1}=280 nm, λ_{ex2}=320 nm, λ_{ex3}=365 nm, and λ_{ex4}=395 nm were selected for subsequent measurements. Emission

spectra were recorded from the excitation wavelength plus 20 nm, to avoid Rayleigh scattering, and up to 600 nm.

LOW FIELD ^1H NUCLEAR MAGNETIC RESONANCE

LF-NMR measurements were performed on a Maran Benchtop Pulsed NMR analyser (Resonance Instruments, Witney, UK), operating at a frequency of 23.2 MHz and equipped with a 18 mm variable temperature probe head. Transverse relaxation, T_2, was measured using the Carr-Purcell-Meiboom-Gill (CPMG; Carr and Purcell, 1954; Meiboom and Gill, 1958) sequence, and longitudinal relaxation (T_1) was measured using the inversion recovery sequence (INVREC; Vold et al. 1968). NMR relaxation data were acquired as 16 scan repetitions for the CPMG pulse sequences and 4 scan repetitions for the INVREC pulse sequences using a two seconds relaxation delay between successive pulse scans. The samples were equilibrated for 20 min. at the desired measurement temperature (26°C) and the sample probe temperature was kept constant at 26^{o}C by a continuous airflow. The meat samples were introduced into the NMR probe by placing cylindrical samples (14 mm diameter), stamped out from the centre of the meat samples into sealed glass tubes, which matched the inner diameter of the 18 mm NMR sample tubes.

DATA ANALYSIS

The numerous spectral data points obtained from the spectrophotometers were processed using multivariate data analysis with the purpose of developing calibration models for predicting the reference information from the water-holding capacity traits and from the chemical composition of the meat. Predictions based on spectral information was performed with partial least squares regression (PLSR), which (after centering of the data) projects the spectral data onto common orthogonal structures, called latent variables, or variable weights, by describing the maximum covariance between the spectral information and the references. In spectroscopy the numerous data points are linearly combined and can thus be reduced to only a few factors called scores. These scores give a more robust and concentrated representation of the samples discarding only a minimum of non-systematic information (Martens and Næs, 1993). The latent variables and the scores combined form the principal components (PC). In this study predictions are validated with full cross validation (leave one out), which is an accepted method for estimating the number of PC and the standard error of prediction (SEP) (Martens and Næs, 1993; Martens and Dardenne 1998). The multivariate data analysis was performed with the chemometric program Unscrambler 7.1 (CAMO, Trondheim, Norway).

Bi-exponential fitting analysis of longitudinal relaxation data were carried out using an in-house program (Bechmann et al., 1998) written in Matlab (The Mathworks Inc., Natick, MA, USA). By this procedure characteristic relaxation time constants, T_{21} and

T_{22}, and their corresponding amplitude parameters, M_{21} and M_{22}, are extracted for each longitudinal (CPMG) LF-NMR measurement.

RESULTS AND DISCUSSION

Statistics of the reference parameters for all the samples combined and separated into four groups by the HAL-genotype and the muscle group is shown in Table 1. The drip loss variation tends to be above the average level for porcine meat in Denmark (Karlsson *et al.* 1997). This is a known effect when including the Halothane gene in a pig population. The two WHC methods are correlated with r=0.61 and this relative low correlation indicates that the two methods represent different information on the WHC in meat as previously discussed by Trout (1988). Where the drip loss reveals the amount of free by gravity exudable water in the muscle fibres, the filter paper method displays the water that is expressable by applying a capillary force to the meat. The force applied in the filter paper method is however too small to cause any damage to the meat structure and can therefore be ruled out as the main origin for the differences observed between the two methods. The filter paper method, however, suffers from a large dependence on the roughness and composition of the meat surface, where the filter paper is applied. This is also reflected in a very large standard deviation (Table 1). The drip loss and filter paper wetness were significantly ($P<0.001$) higher for the LD muscle than for the ST muscle for both genotypes. When inspecting the mean within each muscle, the only significant ($P<0.05$) difference between the genotypes was the higher drip loss for HAL-Nn compared to HAL-NN. Also the IMF seem to be above normal variation especially for the ST muscle. However, low variation in the water content of the meat is observed for both muscles and both genotypes.

Table 1. Overall means and standard deviations for the meat quality.

	All Samples (N=78)		LD				ST			
			Hal-Nn (N=18)		Hal-NN (N=21)		Hal-Nn (N=18)		Hal-NN (N=21)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Drip Loss (%)	6.1	3.2	9.4	1.9	7.1	2.5	4.2	2.5	3.5	2.0
Filter Pap. (%)	38.0	20.4	46.0	23.0	36.7	15.7	36.6	19.9	31.2	21.0
IMF (%)	3.6	1.9	2.7	1.3	2.7	1.5	4.7	2.4	4.5	1.6
Water (%)	72.9	1.4	72.7	1.0	72.7	1.2	73.3	1.4	75.5	2.3

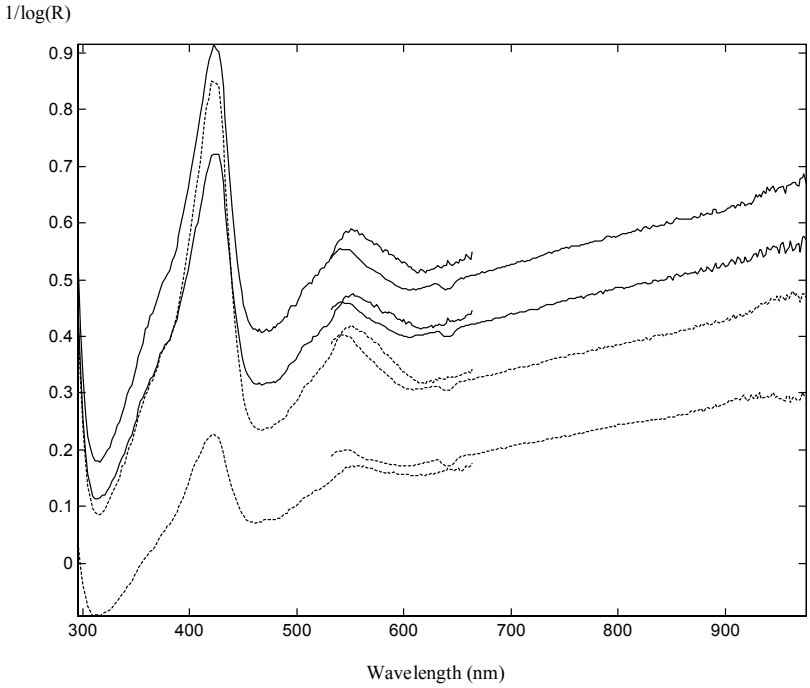

Figure 1. Spectra from two meat samples collected with the FOP system. UV-VIS of the LD muscle (——) and the ST muscle (— —). VIS-NIR of the LD muscle (— - — -) and the ST muscle (------).

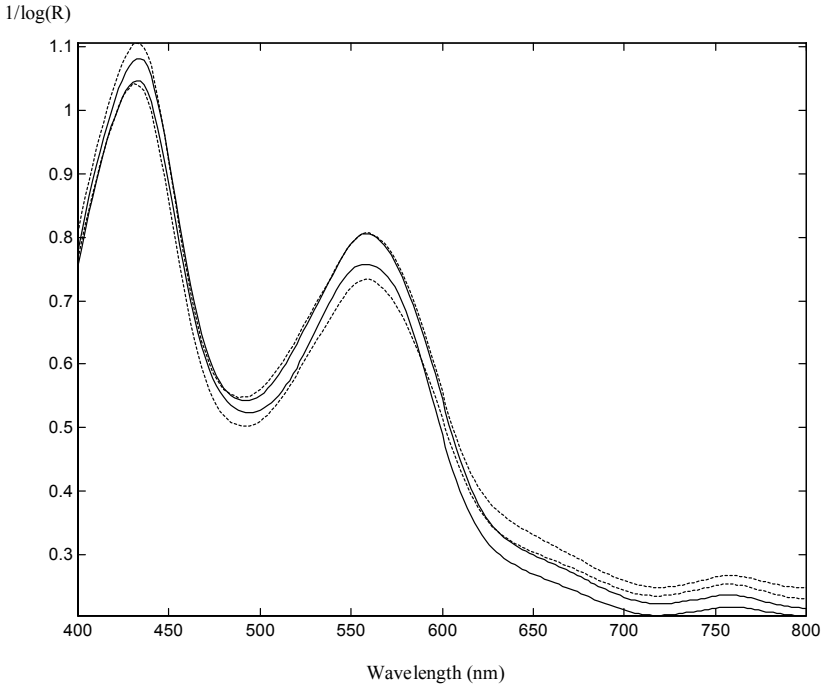

Figure 2. VIS spectra from two meat samples. LD muscle (——) and the ST muscle (— —).

The absorbance FOP spectra for the LD and ST muscles for two normal samples are shown in Figure 1 for both spectroscopic channels. The FOP UV-VIS spectra show two absorbance peaks at 425 nm and 550 nm, whereas the FOP VIS-NIR spectra display only one absorbance peak at 545 nm. The correlation between these two absorbance peaks for the FOP UV-VIS spectra is 0.96. This high correlation indicates that the two peaks are caused by the same phenomenon, most likely deoxymyoglobin. Swatland (1995) reported absorption maxima at 434 nm (for the Soret band) and 555 nm for native deoxymyoglobin. The peaks for the native oxymyoglobin are found at slightly lower wavelengths (418 nm and 544 nm respectively), and these chromophores do not appear in the spectra. Similarly, since no chromophors for denatured metmyoglobin, which in the native state are found 630 at nm (Bertelsen and Skibsted, 1987), are found in the spectra, this state of metmyoglobin are not likely to be found in the meat samples. It appears from the VIS part of the FOP UV-VIS and from the FOP VIS-NIR data, that the absorbance values above 450 nm are higher for the LD samples. This difference between the two muscles is generally observed for all measurements (data not shown) and reflects scattering properties from the muscles. Despite the fact that three insertions are made with the FOP, there is most likely a representation problem with the FOP measurements because of the small area measured.

The NIR Systems VIS spectra for the LD and the ST muscles of two normal samples are shown in Figure 2. Peaks in the log(1/R) data are observed at 430 and 560 nm, thus very close to the absorbance peaks observed for the FOP data (Figure 1). Consistent with the FOP measurements we find again the correlation between the absorbance peaks to be high (r=0.96), and the peaks are thus likely to be caused by the existence of myoglobin.

The NIR spectra of the LD and ST muscles from two samples normal are shown in Figure 3. Local maxima in the NIR data are found at 980 nm *(O-H stretch, second overtone)*, 1450 *(O-H stretch, first overtone)*, 1920 nm *(O-H stretch + O-H deformation)* (all due to water) and 1200 nm *(C-H stretch second overtone)* and 1800 nm *(C-H stretch first overtone or combination band)*. Protein information is usually found around 1500 nm (N-H stretch, first overtone) and above approx. 2000 nm (combination bands), but the protein information in the spectra of Figure 3 seem to be immersed in water information. Spectral differences between LD and ST are mainly due to the scatter properties.

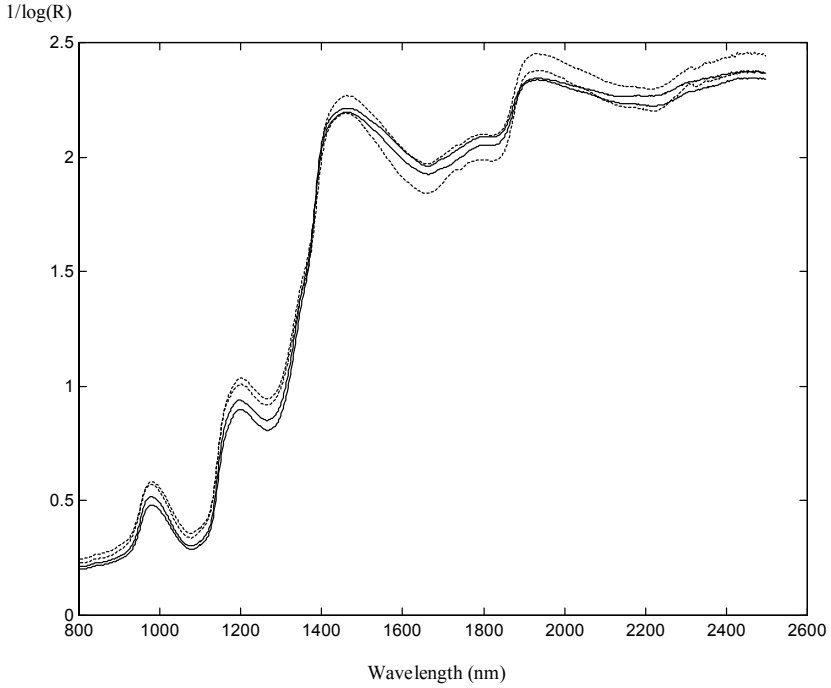

Figure 3. NIR spectra from two meat samples. LD muscle (——) and the ST muscle (— —).

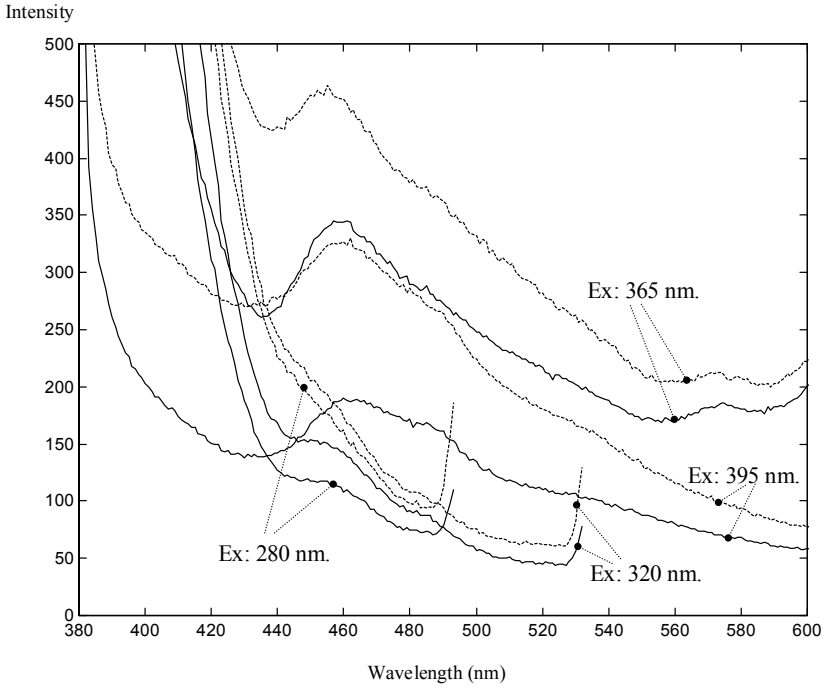

Figure 4. The four fluorescence spectra from on sample. LD muscle (——) and the ST muscle (— —).

Fluorescence spectra of both muscles from the same pig are shown in Figure 4 for both muscles. Fluorescence emission peaks are observed at 460 nm for λ_{ex}=280 nm, at

460 nm for λ_{ex}=320 nm, at 455 nm for λ_{ex}=365 nm, and 460 nm and 485 nm for λ_{ex}=395 nm. Thus, the most significant fluorophore is observed around 460 nm for all excitations. Two factors are believed to contribute to the fluorescence. Firstly, the respiratory enzyme NADH, which is a bi-product of the muscle metabolism. An emission peak at 460 nm for excitation 366 nm was explained by NADH by Jensen et al. (1989). Swatland (1995a) explained fluorescence emission peaks in beef at 440 nm (excitation at 375 nm) with the presence of connective tissue (collagen type I and III). The Rayleigh peaks for especially λ_{ex}=280 nm, and λ_{ex}=320 nm are very wide, and for the ST sample, the fluorescence signal almost submerge into the Rayleigh signal. This is likely to be due to the scatter effect from the UV reflection of the fat, which is supported by the higher effect observed for the ST sample (see Table 1). Higher level of connective tissue in ST than in LD is also most likely a main factor for the separation of the two muscle types from the fluorescence signal. Scrutinising of the NADH fluorescence parameter (ex. 395, em. 460 nm), we found no separation between the HAL-NN and HAL-Nn was observed.

LF-NMR on high water content samples such as meat generally provides information on the state of the water, or more precisely diffusive domains, in the samples. The LF-NMR relaxation curves for LD and ST from two pigs are shown in Figure 5a and 5b. From both the INVREC (T_1) relaxation (Figure 5a) and the CPMG relaxation (Figure 5b) curves a difference between the LD and the ST muscles are observed in the spectra.

Bi-exponential analysis (two component model) of the CPMG relaxation curves were judged to be appropriate to describe the muscle samples. The CPMG measurements were initially performed using 5 different values of tau, which is half of the 180° interpulse spacing. Figure 6 displays the tau dependence of the four fit parameters: T_{21}, T_{22}, M_{21} and M_{22} on one selected sample. As apparent from the figure there is a linear response regime between 100 and 1000 μs and accordingly we have selected the CPMG relaxation at tau equal 500 μs for subsequent analysis. The statistics for the amplitude (M_{21} and M_{22}) and the time variables (T_{21} and T_{22}) are shown in Table 2. A significant ($P<0.01$) difference between the two muscles are seen for M_{22}, T_{21} and T_{22}, however most prominent for T_{21}. Figure 7 shows T_{21} for all 52 samples displaying a clear separation between LD and ST (mean of 38 ms and 43 ms respectively) muscles due to a small but very distinct difference. This is very interesting as T_{21} previously has been related to sensory and rheological attributes of meat and assigned to intracellular water (Tornberg et al., 1993).

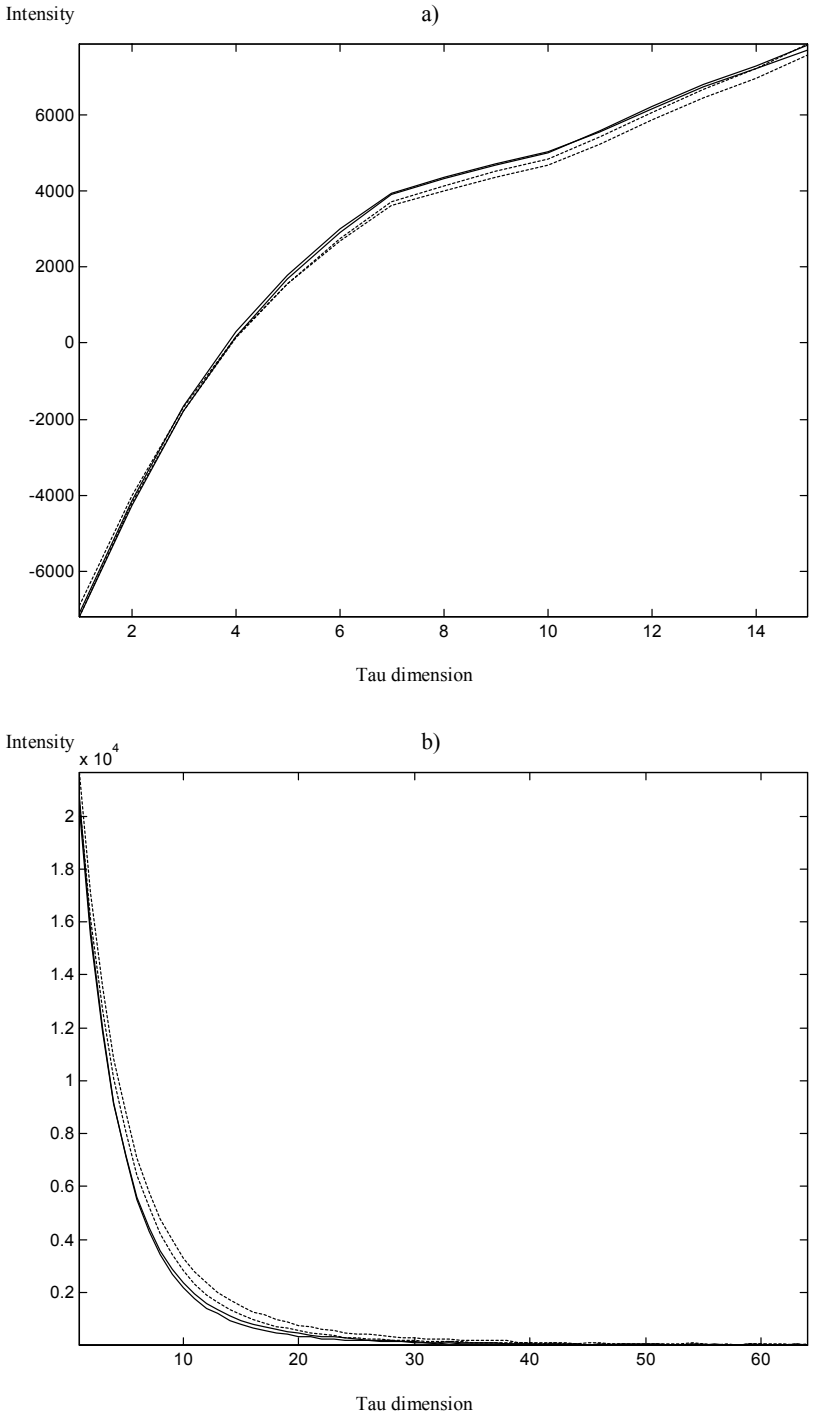

Figure 5. LF-NMR data from two samples. a) INVREC. b) CPMG. LD muscle (——) and the ST muscle (— —).

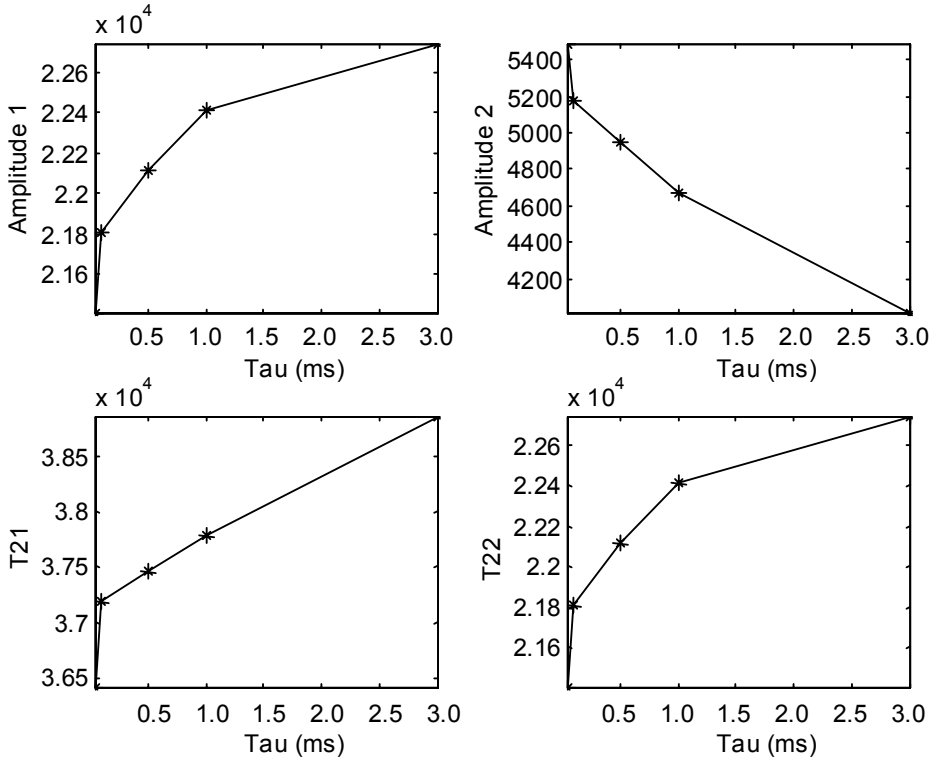

Figure 6. Tau versus amplitude plots for the LF-NMR CPMG data.

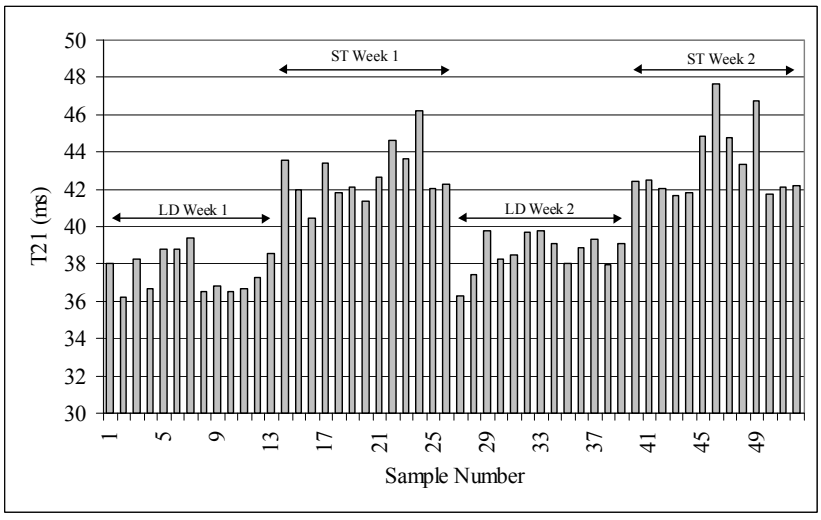

Figure 7. The T21 values for all 52 samples measured with the LF-NMR CPMG data. A difference between the LD and ST muscles is observed.

Table 2. Overall means and standard deviations for the LF-NMR fit parameters.

	All Samples (N=52)		LD				ST			
			Hal-Nn (N=13)		Hal-NN (N=13)		Hal-Nn (N=13)		Hal-NN (N=13)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
M_{21}	4935	197	4989	254	4926	170	4901	89	4917	232
M_{22}	1033	59	948	154	963	84	1117	180	1118	124
T_{21} (ms)	40.5	2.9	38.0	1.1	38.2	1.2	43.4	2.0	42.9	1.68
T_{22} (ms)	103.5	12.3	98.6	6.8	94.6	10.5	112.9	14.2	109.2	8.1

The type of the muscle fibre has often been related to meat quality (Swatland, 1995a). Petersen *et al.* (1996) reports 81% and 74% Type IIB muscle fibres for LD and ST, respectively. This fibre type is glycolytic and consistent with the lower WHC for LD compared to ST (see Table 1). However, the difference in fibre type proportions does not account for the significant difference in T_{21}. Petersen *et al.* (1998) also reported a significant higher mean cross-sectional area for the muscle fibre types in ST (5358 μm^2) than in LD (4763 μm^2). While T_{21} is a quality parameter giving information of the diffusive restrictions within the muscles it is highly likely that T_{21} is directly related to the geometric restrictions within the myofibrils of the muscles. We therefore propose that it is this characteristic difference in the diameter between the two muscles, which is measured by the difference in the T_{21}. There is a close proportional relation between the cross-sectional fibre area of two muscles and the T_{21}. This preliminary conclusion is supported by a recent LF-NMR study on beef, where an intermediate early post-mortem swelling in the myofibrillar system causing the mean cross-sectional area to increase is followed by an increase in T_{21} (Tornberg *et al.* 1999). Thus, the LF-NMR (T_{21}) describes the water diffusion within the myofibrillar system of the muscle.

Table 3 presents the prediction results for the investigated spectroscopic techniques. For the WHC parameters, LF-NMR was superior among the spectroscopic techniques with correlation values of 0.74 to drip loss and 0.53 to filter paper wetness. Compared to a repetition coefficient of r=0.89 for the drip loss method and 0.88 for the filter paper method (Karlsson, unpublished results) the prediction results are encouraging. It is interesting to observe that the CPMG measurements result in a slightly better performance than the T1 measurements (except for the IMF predictions). The CPMG data is acquired in few seconds, whereas the acquisition time for the T1 data exceeded 5 min. Thus, the industrial use of the CPMG data is more realistic. Exponential data fitting is the usual approach for analysing LF-NMR relaxation curves. However, for predictive purposes, there tend to be an improvement by including the entire information of the relaxation curves in a multivariate calibration. As seen in Table 3, all four reference parameters are predicted better with the multivariate analysis, than by using the quantitative parameters from the exponential fit (M_{21} and M_{22}) which is

in good agreement with investigations made by Jepsen *et al.* (1999) measuring NMR on intact Salmon meat.

Table 3. Correlation coefficients (r) and standard error of prediction (SEP) and number of principal components (PC) in the PLSR models. SEP values are absolute (%).

	Drip Loss			Filter Paper			IMF			Water		
	r	SEP	#PC	r	SEP	#PC	r	SEP	#PC	r	SEP	#PC
FOP	0.61	2.53	4	0.26	12.92	2	0.15	6.29	1	0.35	1.17	1
VIS	0.72	2.14	2	0.54	18.04	2	0.52	1.61	3	0.46	1.05	4
NIR	0.64	2.43	4	0.62	16.01	4	0.70	1.32	5	0.46	1.13	4
Fluorescence	0.68	2.27	5	0.43	10.41	3	0.57	1.09	4	0.16	0.93	1
Exp. fitting	0.72	2.14	2	0.61	17.11	2	0.57	1.43	3	0.55	0.97	2
CPMG	0.75	2.03	3	0.53	18.55	3	0.68	1.27	3	0.67	0.83	1
T1	0.74	2.07	3	0.46	19.35	2	0.77	1.13	3	0.64	0.92	2

According to Trout (1988) NMR is a useful tool for measuring water binding relations, but considerations of the compositional characteristics is necessary for the further interpretation. This argument is strongly supported by the influences from the cross-sectional muscle fibre diameter on the T_{21} shown here.

The results obtained for the VIS data are encouraging for the drip loss values. The success is expected to reside in the indirect relation between the light scattering and the extra-cellular space, where some of the drip fluid is contained. Monochromatic reflectance and colour meters have been investigated in relation to WHC (Swatland 1995a). Monochromatic measurements are troubled by the strong effect from myoglobin, and colour meters are optimised for reproduction of colour interpretation by the human eye, and this optimisation is justified when evaluating the response of consumers to the meat quality, but are not necessarily optimal for prediction of WHC. The results obtained in this study indicate that the VIS data indirectly can be related to WHC using the multivariate calibration.

When observing the HAL-Nn samples separately the correlation generally increases due to the increased variation as displayed in Table 1. E.g. the correlation for the LF-NMR INVREC data improved to r=0.81 by inspecting the HAL-Nn group alone due to the increased variation.

The prediction of the composition parameters is also most successful with the LF-NMR data. The results are not quite as promising as those reported by Jepsen *et al.* (1999) on fish meat using the same equipment. However, this difference most likely resides in the much higher variation in the fish data (IMF varying from 2% to 42% and water varying from 39% to 77%). Also the NIR data showed good predictions of IMF but failed on the water predictions.

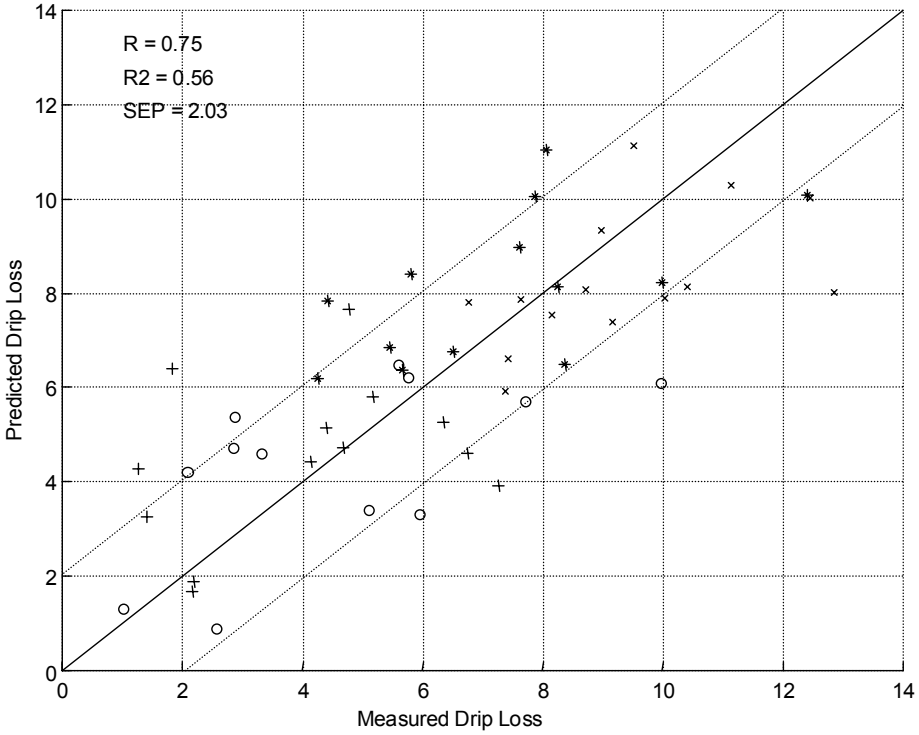

*Figure 8. Measured versus predicted drip loss with the LF-NMR CPMG data. The middle diagonal line shows the regression line, and the two dotted diagonal lines show the prediction errors. The labels indications are *: LD HAL-NN, ×: LD HAL-Nn, +: ST HAL-NN, o: ST HAL-Nn*

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The FOP measurements are interesting from an on-line point of view. The technique performs better with regard to WHC than the composition measures. This observation is due to the poor sample representation of the FOP measurement in the meat (despite three insertions in the meat), with a measured area with a diameter of only 2 mm.

The results presented are encouraging for further research in spectroscopic methods for rapid measurement of functional meat quality and composition. Especially the LF-NMR and the VIS reflectance predictions are promising. Much effort is still required before the industrial use of the techniques can be introduced. However, in order to improve spectroscopic methods, it is necessary to improve the repeatibility and to understand in more detail the rather unspecific reference methods for determination of the WHC characteristics, e.g. by advancing the methods described by Trout (1988) for complementary use for WHC characterisation. In on-line situations the VIS technique tends to be the more readily applicable, but there is still a problem with the sampling technique and the meat representation to overcome. The LF-NMR sampling is advantageous in being a volume based rather than a surface based measurement,

which was clearly observed from the composition predictions. The CPMG technique provides a relative rapid assessment of the T_2 relaxation but the destructive sample preparation is a disadvantage. Ultimately, the spectroscopic technique should be applicable earlier post-mortem, preferably at 30-45 minutes before the carcasses are transported to the cooling facilities.

CONCLUSION

The use of spectroscopic techniques for rapid assessment of water-holding capacity (WHC) and composition of two porcine muscles (LD and ST) has been outlined in this paper. Visual reflectance and fluorescence provided reasonable accurate predictions of WHC. Near infrared reflectance predicted the intramuscular fat (IMF) reasonably well. The fibre optical probe and the fluorescence measurements suffered critically by the low sample representation due to the heterogeneity of the meat. The most successful technique for prediction of WHC, IMF and water contents was ^{1}H low-field nuclear magnetic resonance. The T21 exponential fit parameter was directly related to the myofibrillar spacing in the muscles.

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