ELSEVIER

Food Chemistry 69 (2000) 427–436

Food Chemistry

www.elsevier.com/locate/foodchem

Prediction of beef quality attributes from early post mortem near infrared reflectance spectra

R. Rødbotten *, B.N. Nilsen, K.I. Hildrum

MATFORSK, Osloveien 1, N-1430 Ås, Norway

Abstract

The potential of predicting beef quality attributes after ageing from early post mortem near infrared (NIR) reflectance spectroscopy (1100–2500 nm) has been studied. Altogether, 127 hot boned, *Longissimus dorsi* muscles from both bulls and cows were investigated in two separate studies. 36 of these carcasses were low voltage electrically stimulated. NIR recordings were obtained 2–30 h post mortem on fresh, sliced loin, while the quality assessments were performed after 2 or 7 days ageing at 4°C on frozen/thawed beef. Spectral changes during rigor mortis were not related to the ageing potential of the individual loin samples. Predicting final tenderness from NIR spectra recorded at different post mortem times yielded predictive models. However, the multivariate correlation coefficients of the models were relatively low, for example, Warner–Bratzler (WB) shear press measurements ranged from 0.47 to 0.55. Making separate prediction models based on genders yielded models for WB shear press with correlation coefficients up to 0.68. Prediction from sensory tenderness gave prediction models with lower correlation coefficients. Intramuscular fat content in intact meat was predicted with correlation coefficients of 0.78-0.85, and prediction errors (RMSEP) of 1.2–1.4%. The results obtained in this study do not support that early post mortem NIR spectroscopy can be used as precise predictor of final tenderness.

1. Introduction

The quality of red meat offered for sale in many countries is highly variable. Breed, age, sex and feeding are some of the pre slaughter factors which influence the quality (Boleman, Miller, Buyck, Cross & Savell, 1996; Jeremiah, Tong & Gibson, 1991; Shackelford, Koohmaraie, Wheeler, Cundiff & Dikeman, 1994; Shorthose & Harris, 1990). Fat is important for the eating quality of beef, and fat content is used for carcass classification in many countries. Marbling score is the trait with the highest influence on USDA quality grades of beef carcasses (May, Dolezal, Gill, Ray & Buchanan, 1992). While fat marbling does not change after slaughter, beef tenderness is influenced by post slaughter treatment. The conditions during rigor development are the most important factors in beef tenderisation and ageing (Dransfield, 1994), and tenderness is the single most important quality parameter for consumer acceptance. Studies have shown that customers are willing to pay a higher price for beef with guaranteed tenderness (Boleman et al., 1997; Morgan et al., 1991).

It is hardly possible for a slaughter operation to secure optimal conditions relating quality for all carcasses. A method used early during processing, that could predict tenderness of beef at the time of consumption, would be beneficial for both consumers and the industry. The carcasses that will not tenderise to an acceptable level after ageing could then be identified and used for other purposes.

An efficient method for tenderness assessment should be rapid, non-destructive and reliable. The ultimate quality test is evaluation by consumers, but this is hardly possible to implement for practical use. Muscle temperature (Lochner, Kauffman & Marsh, 1980; May et al., 1992) and muscle colour (Jeremiah et al., 1991; Wulf, O'Connor, Tatum & Smith, 1997) have not been found to be useful predictors for tenderness. There are diverging results on using early post mortem pH as a predictor for tenderness (Jones & Tatum, 1994; Shackelford, Koohmaraie & Savell, 1993). The most widely used mechanical method for tenderness is the Warner–Bratzler (WB) shear force test. This test shows a high correlation with sensory panel scores (May et al., 1992; Shackelford, Wheeler & Koohmaraie, 1995). However, the WB shear force method is destructive and time consuming.

* Corresponding author.

0308-8146/00/$ - see front matter
PII: S0308-8146(00)00059-5

Near infrared (NIR) spectroscopy has been used for assessment of fat, moisture and protein in emulsified or ground meat (Bjarnø, 1982; Kruggel, Field, Riley, Radloff & Horton, 1981; Lanza, 1983). In recent years, new applications of NIR spectroscopy for estimation of textural and sensory characteristics in intact beef cuts have emerged (Byrne, Downey, Troy & Buckley, 1998; Hildrum, Nilsen, Mielnik & Næs 1994; Hildrum, Isaksson, Næs, Nilsen, Rødbotten & Lea, 1995; Mitsumoto, Maeda, Mitsuhashi & Ozawa 1991; Park, Chen, Hruschka, Shackelford & Koohmaraie, 1998). Most of these studies report results regarding correlations between NIR spectra and textural and sensory analysis that were sampled at the same point in time. However, Byrne et al. used NIR spectra (750–1098 nm), which were recorded 1, 2 and 7 days after slaughter to predict tenderness, as measured 14 days post mortem.

The early detection of carcasses that will not age well is highly desired. No studies have been identified in the literature where NIR spectra of beef have been recorded pre rigor or earlier than 24 h post mortem. The aim of this study was therefore to examine if NIR reflectance spectra (1100–2500 nm), measured earlier than 24 h post mortem, could be used to predict final tenderness. We also wanted to determine if NIR spectroscopy could predict intramuscular fat content of intact (not ground) beef.

2. Materials and methods

In total, samples from *Longissimus dorsi* muscles from 127 carcasses of the Norwegian Red breed were collected at random at a commercial slaughterhouse. In the first study, 79 loins in five subsets (10–24 carcasses in each) were collected over a 1-year period. To examine the effect of collecting all samples within a short time frame, the remaining samples from 48 carcasses were collected over a period of 3 days.

2.1. Study 1. Five subsets of samples collected over a year (n = 79)

Because the analyses were very time consuming, it was difficult to include a high number of samples in each set. Both bulls (37) and cows (42) were included to span a wide sample space. Carcasses from 7 cows and 5 bulls were electrically stimulated 10–12 min after stunning (90 V, 15 Hz, 32 s, MITAB, Sweden). The current was applied through a clip in the nostrils and by shackling of one leg. Approximately 45 min after stunning the muscles were excised from the bones, packed in polyethylene bags and conditioned for 26 h at 15°C. The samples were further aged at 4°C for up to 7 days after slaughter.

Continuous NIR reflectance spectra were recorded transversally to the muscle fibres on freshly cut samples 4 and 26 h post mortem. WB shear press was measured 2 and 7 days after slaughter, and sensory analysis after 7 days. The rates of pH and temperature fall were monitored up to 48 h, and samples for sarcomere length were taken at 48 h.

2.2. Study 2. One sample set collected over 3 days (n = 48)

The samples from 48 carcasses were collected during 3 consecutive days. Half of the carcasses each day were electrically stimulated. There were an equal number of samples from bull and cow carcasses each day. To obtain true pre rigor measurements, the first NIR recording was done 2 h post mortem. For practical reasons, 30 h was chosen for the post rigor measurement. Otherwise the procedures were as in study 1.

2.3. NIR reflectance analysis

The samples were cut to make the muscle fibre direction parallel to the measurement surface. A slice with approximate thickness of 1.5 cm was made, and this piece was again cut into a circular shape of 4–5 cm in diameter. The samples were mounted in a specially designed cup for analysis of intact beef samples and covered with quartz glass. This preparation procedure ensured that the NIR light beam was directed transversally to the muscle fibres. The area that was illuminated was approximately 1 cm^2. NIR reflectance spectra were obtained in the 1100–2500 nm range at 4 nm intervals with an InfraAlyzer 500 spectro-photometer (Bran & Luebbe GmbH, Norderstedt, Germany). Spectrophotometer control and preliminary spectral file handling was performed using Sesam software (version 3.01). From each sample five spectra were recorded at different locations.

2.4. Texture measurements

For texture analyses the samples were vacuum-packed in polyethylene bags, heat-treated in water bath at 70°C for 50 min, cooled in running ice water for 50 min, frozen and stored at −40°C. Before analysis the samples were thawed overnight at 4°C and stabilised for at least 30 min at 20°C before measurements. Heat treated muscles were sliced into pieces of 1 cm thickness along the fibre direction. The second cut was also done in the fibre direction to give samples with a cross-sectional area of 1 × 1 cm^2. Structures of visible fat and sinew were avoided. Ten parallels were sheared at right angles to the fibre direction with the WB shear-press device in an Instron Materials Testing Machine (Model 4202, Instron Engineering Corporation, High Wycombe, UK). The mean value from these 10 parallels of the maximum force readings was used in the data analysis.

2.5. Sensory analysis

The sensory attributes tenderness, hardness and juiciness were assessed on samples served at 20°C, which were prepared in the same way as for the texture analysis described above. While hardness refers to the first bite, tenderness relates to the whole chewing process. 10–11 trained assessors using a sensory profile method (ISO 6564-1985) performed the sensory analyses on duplicate samples. The sensory intensity scale was from 1 (low intensity) to 9 (high intensity). The intensity scores over assessors and replicates were used in the regressions.

2.6. Other analyses and registrations

Sarcomere lengths were measured on samples aged for two days by the laser-diffraction method described by Gif, Tournayre and Cuioli (1995). Samples for pH measurements were cut into small pieces with a scalpel and dispensed in neutralised 5 mM sodium iodoacetate/150 mM potassium chloride solution, (Bendall, 1973). The pH of the homogenate was measured using a Beckman ϕ31 pH-meter with a Mettler Toledo electrode. The temperatures in the surroundings and in the meat samples were monitored during the ageing process with temperature loggers (EBI 125 A, ebro Electronic GmbH, Ingolstadt, Germany and CR10X, Campbell Scientific Inc., Leicestershire, UK). The needles were inserted into the middle of the loins. Fat content of the samples was determined on homogenised and dried samples of the muscles by NMR (Bruker Minispec pc 120, Rheinstetten, Germany).

2.7. Data analysis

The data were analysed using the Unscrambler software package (version 6.11b, Camo A.S, Trondheim, Norway). Partial least-squares regression (PLS) was used in predicting sensory and textural properties from NIR spectra. Full cross validation was used in the validation method. This segmentation procedure puts one sample at a time in the test set of the calibration. Multiplicative scatter correction (MSC), which corrects for both multiplicative and additive scatter effects in the spectra, was used to reduce irrelevant noise in the spectra (Martens & Næs, 1989). The predictive accuracy of the models is given by the root mean square error of prediction (RMSEP).

3. Results and discussion

3.1. Ranges of the samples

Results from analysis of quality parameters are shown in Table 1. There were large variations in carcass weights. The mean weight was significantly higher for bulls than for cows. Cows had higher fat content than bulls. The average WB shear forces were significantly higher for bulls at both 2 and 7 days than for cows in study 1, but not in study 2. Sensory tenderness values confirmed these results. The variation in sensory juiciness was small. WB shear press and sensory tenderness values were negatively inter-correlated in study 1, with correlation coefficients of −0.90 and −0.80 for 2 and 7 days, respectively. This showed that WB shear press was an acceptable measure of tenderness, and thus was the sole tenderness measure in study 2. In study 1 the average pH measured after 3 h was 5.96 for the electrically stimulated carcasses while the average for the unstimulated samples was 6.44. The faster pH drop for the stimulated carcasses indicates that these samples went into rigor earlier than the rest. Low voltage electrical stimulation had also a positive effect on tenderness. However, the influence of electrical stimulation, gender and temperature on final tenderness will be published in the near future.

3.2. Study 1. Results from five subsets of samples collected over a year

3.2.1. Observations on NIR spectra

The average NIR spectra at 4 and 26 h are shown in Fig 1. These are typical NIR reflectance spectra of meat with broad absorbance bands, which are overlapping overtone and combination bands originating from the IR wavelength region. Water molecules mainly absorb light in two areas, at approximately 1450 and 1950 nm. Overlapping bands from proteins and fat contribute to the absorbance around 1200, 1700–1800 and 2200–2400 nm.

In the wavelength region between 1100 and 1900 nm there was a difference between the raw spectra recorded at 4 and 26 h post mortem. A substantial decrease in absorbance was observed during this period. Time of onset of rigor mortis varies widely between carcasses, but 4 h post mortem is before or in the beginning of rigor mortis for most carcasses. During rigor mortis, shortening of myofibrils and cross-bridge formation gives a more compact structure in the muscle, which shortens the penetration length of light into the muscles. Because of shrinkage of the muscle, water will leak from the muscle cells into the extracellular space. The displacement of water may result in light scattering in the tissue, which also contributes to reduced light absorbance. Endogenous proteases in the muscles start to break down the proteins soon after slaughter (O'Halloran, Troy, Buckley & Reville, 1997). The activities of these enzymes disrupt the structure of some proteins, which then may form agglomerates. These new structures will have a different absorbance of light, which may reduce penetration depth of light into the muscle.

Table 1
Range of properties for all 127 *M. Longissimus dorsi* samples

	Constituent/property	Unit	Range	Mean	*n*
Study 1. (Five subsets of samples collected over a year, n = *79)*					
Bulls					
	Carcass weights	kg	227–477	309	37
	Fat content of loins	%	0.8–5.9	1.9	37
	Sarcomere length	μm	1.28–1.99	1.80	33
	pH 4 h p.m.		5.82–6.92	6.47	37
	pH 26 h p.m.		5.39–6.06	5.54	37
	WB shear press (2 days)	kg 10^{-1} cm^{-2}	43–112	69	37
	WB shear press (7 days)	kg 10^{-1} cm^{-2}	29–97	57	37
	Sensory hardness	Intensity	3.0–6.4	4.6	13
	Sensory tenderness	on scale from	3.5–7.5	5.7	13
	Sensory juiciness	1 to 9	4.4–5.8	5.2	13
Cows					
	Carcass weights	kg	155–341	262	42
	Fat content of loins	%	1.0–14.8	4.4	42
	Sarcomere length	μm	1.29–1.98	1.78	38
	pH 4 h p.m.		5.41–6.77	6.28	42
	pH 26 h p.m.		5.32–5.70	5.47	42
	WB shear press (2 days)	kg 10^{-1} cm^{-2}	27–91	54	42
	WB shear press (7 days)	kg 10^{-1} cm^{-2}	26–80	46	42
	Sensory hardness	Intensity	2.3–5.8	3.9	16
	Sensory tenderness	on scale from	4.3–8.0	6.5	16
	Sensory juiciness	1 to 9	4.7–5.9	5.3	16
Study 2. (One sample set collected over 3 days, n = *48)*					
Bulls					
	Carcass weights	kg	241–367	308	24
	Fat content of loins	%	1.3–5.2	2.1	24
	pH 2 h p.m.		6.30–7.05	6.66	24
	pH 6 h p.m.		6.04–6.69	6.39	24
	pH 30 h p.m.		5.47–6.33	5.70	24
	WB shear press (2 days)	kg 10^{-1} cm^{-2}	41–132	78	24
	WB shear press (7 days)	kg 10^{-1} cm^{-2}	30–120	52	24
Cows					
	Carcass weights	kg	153–376	237	24
	Fat content of loins	%	1.2–10.6	3.7	24
	pH 2 h p.m.		6.05–6.99	6.51	24
	pH 6 h p.m.		5.68–6.83	6.31	24
	pH 30 h p.m.		5.48–5.83	5.62	24
	WB shear press (2 days)	kg 10^{-1} cm^{-2}	48–99	71	24
	WB shear press (7 days)	kg 10^{-1} cm^{-2}	38–82	53	24

3.2.2. Prediction of WB shear press and sensory tenderness from NIR spectra

Table 2 shows the prediction results for WB shear force from early post mortem NIR spectra. Models with predictive ability were found, but the correlation coefficients were relatively low. MSC has been reported to improve the prediction results of NIR spectra from food (Isaksson & Næs, 1988). Performing MSC on the NIR spectra seemed to increase the values of the correlation coefficients, but also increased the number of principal factors in the models. In general, models with few factors will be more robust than models with many factors — in particular in small sample sets. However, models with up to 10 factors were assumed to be acceptable with 79 carcass samples in the prediction set. RMSEP, which is the prediction error in future measurements, was in the range 14–17 kg 10^{-1} cm^{-2} for these models. Similar prediction results were obtained with principal component regression (PCR) as regression method, but the number of principal components in the models was higher than with PLS. Regressions between NIR difference spectra (4–26 h) and tenderness after 7 days or the difference between WB shear force at 2 and 7 days did not yield models with predictive power. This showed that the NIR difference spectra did not contain essential information about final tenderness of the aged samples. Thus NIR spectral changes during rigor mortis were not related to the ageing potential of the individual loin samples.

Although considerable variations in corresponding correlation coefficients was reported also by Byrne et al. (1998), their coefficients seem to be higher than the values reported in this paper. They used NIR spectra in the range 750–1098 nm. It is possible that the shorter

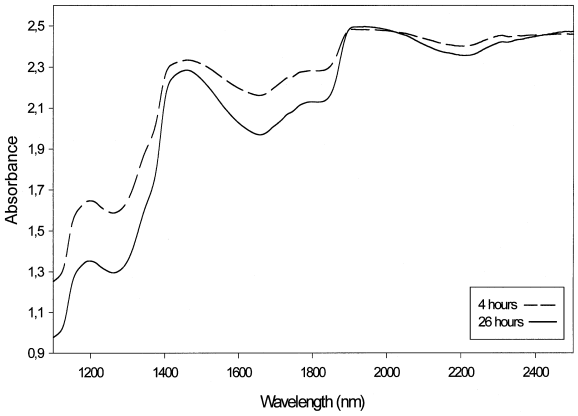

Fig. 1. Average NIR spectra measured 4 and 26 h post mortem in study 1.

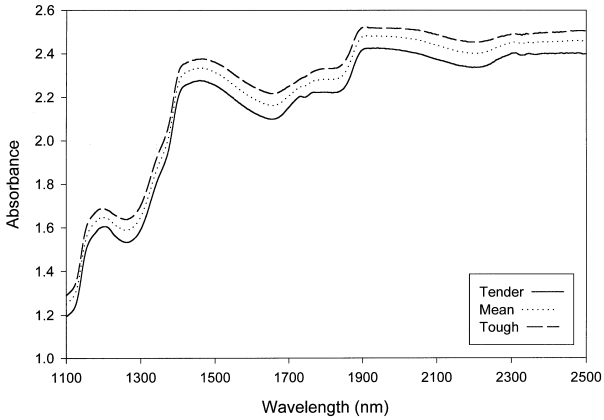

Fig. 2. Average NIR spectra recorded 4 h post mortem for the averages of 10 most tender and 10 toughest carcass samples compared to the average NIR spectrum of all samples in study 1.

wavelength region contains more predictive information about tenderness than the longer wavelength region. Another reason might be that these authors used a more homogenous animal material, i.e. heifers of similar age, size and grade. In our study, the random sampling from a regular slaughter line included animals of a wide range of age from both genders.

The gender's influence on the prediction results was examined by making separate models for cows and bulls (Table 2). However, no systematic difference in prediction of tenderness between genders was observed. Predicting WB shear press from MSC spectra, recorded after 26 h from separate bull or cow sample sets, gave models with correlation coefficients up to 0.68.

Fig. 2 shows the 4 h NIR spectra for the averages of 10 most tender and 10 toughest carcass samples, compared to the average NIR spectrum of all carcasses. WB shear force at day 2 was used as criteria for this classification. On average, the tender samples had lower absorbance than the tough samples over the whole spectral region. The same picture was observed when WB shear force after 7 days was the basis for the classification. The difference in overall NIR absorbance between tender and tough samples was smaller for the 26 h NIR spectra. Similar NIR spectral differences between tough and tender samples have been observed earlier, when NIR spectra was recorded at the same time

Table 2
Prediction of WB shear press values from NIR reflectance spectra of study 1[a]

	n	X-matrix	Y-matrix	Correlation coefficient	RMSEP	Optimal no. of factors
All samples						
	79	NIR 4 h	WB 2 days	0.37	17.4	1
	79	NIR 4 h	WB 7 days	0.49	15.4	4
	79	NIR 26 h	WB 2 days	0.45	17.0	5
	79	NIR 26 h	WB 7 days	0.59	14.2	5
All samples MSC						
	79	NIR 4 h	WB 2 days	0.50	17.1	9
	79	NIR 4 h	WB 7 days	0.52	15.8	10
	79	NIR 26 h	WB 2 days	0.60	15.4	9
	79	NIR 26 h	WB 7 days	0.61	14.2	9
Bulls MSC						
	37	NIR 4 h	WB 2 days	–	–	–
	37	NIR 4 h	WB 7 days	0.42	16.8	4
	37	NIR 26 h	WB 2 days	0.65	14.3	9
	37	NIR 26 h	WB 7 days	0.68	13.6	6
Cows MSC						
	42	NIR 4 h	WB 2 days	0.46	14.3	2
	42	NIR 4 h	WB 7 days	0.34	15.0	2
	42	NIR 26 h	WB 2 days	0.35	16.4	5
	42	NIR 26 h	WB 7 days	0.67	12.0	10

[a] Partial least square regression, full cross validation (— when $r < 0.20$).

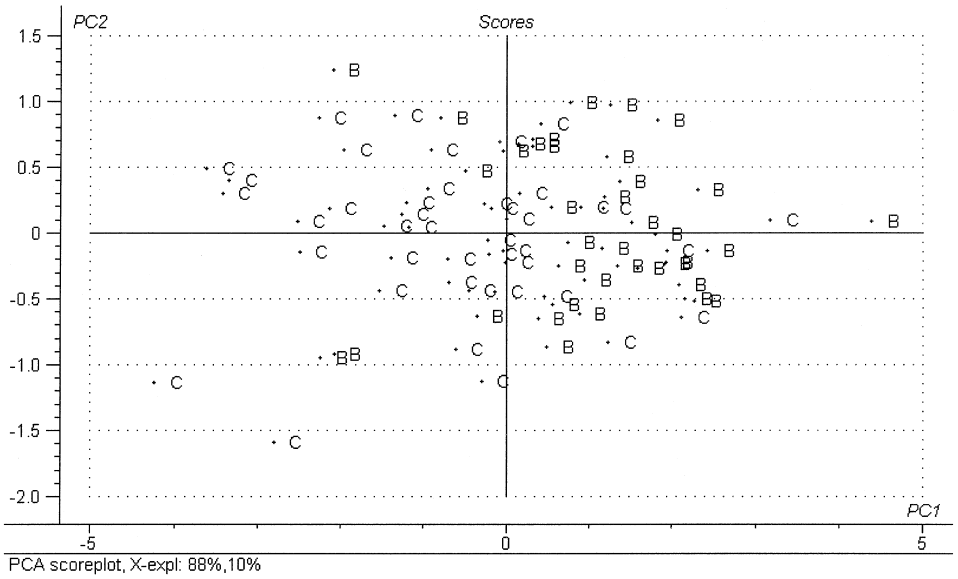

Fig. 3. PCA scoreplot of first and second principal component of NIR spectra recorded 4 h post mortem (C = cow, B = bull).

(i.e. 7 days) as WB shear press measurements (Hildrum et al., 1994). There were only five samples that had sarcomere length shorter than 1.5 μm, and these samples were not among the toughest. On the contrary, two of the toughest samples were among those with longest sarcomeres. In this experiment there was no significant difference in the sarcomere length between samples with high or low WB shear force values. This was probably a result of controlled temperature at 15 °C during rigor. As long as cold shortening conditions are avoided, sarcomere length seems not to be a robust indicator of tenderness. Diverging results have also been reported by Smulders, Marsh, Swartz, Russell and Hoenecke (1990).

The PCA scoreplot of the 4 h NIR spectra shows that the first principal factor seems to differentiate between genders (Fig. 3). In the left part of the score plot few bulls are present, while they dominate on the right side. This ability to differentiate is probably partly based on the indirect effect of different fat contents in cows and bulls. However, the corresponding scoreplot for 26 h NIR spectra did not show the same ability to differentiate between genders. This could be a result of solidification of the intramuscular fat, which would alter light absorbance.

Prediction models for the sensory variables tenderness, hardness and juiciness after 7 days of ageing were made. No models were found for sensory juiciness. In contrast, tenderness and hardness were highly negatively correlated ($r = -0.99$). Correlation coefficients were 0.44 and 0.34 when sensory tenderness was predicted from 4 and 26 h NIR spectra, respectively. Corresponding values for sensory hardness were 0.51 and 0.38. The optimal models contained only one or two PLS factors, which means that no relevant information was found in later factors. MSC of the NIR data offered no improvements in the predictions. Standard errors for the three sensory variables were 0.66, 0.96 and 1.13 for juiciness, hardness and tenderness, respectively.

A separate model was made for 12 carcasses that had been electrically stimulated. When both 4 and 26 h NIR spectra were used in the same model, the correlation coefficients were 0.83 and 0.88, for tenderness and hardness, respectively. The numbers of factors in these models were 5 and 6, which were assumed to be too high for a subset of this size. The reliability of such models is very uncertain, because of high risk of overfitting of data and error modelling. Models made from non-stimulated carcasses had low correlation coefficients with one optimal factor.

It was noted that prediction of tenderness from NIR spectra in some of the single subsets showed much higher correlation coefficients, up to 0.90, compared with the pooled sample set. A similar effect was also

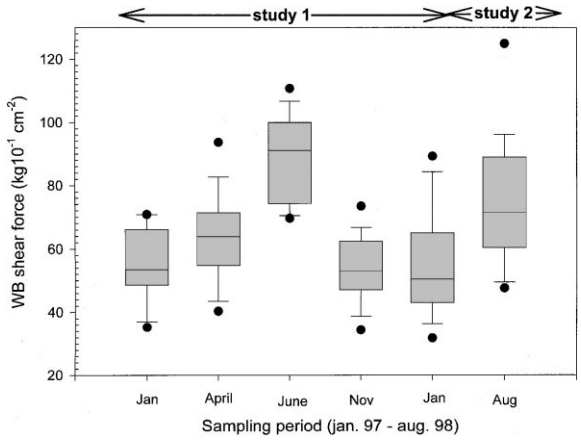

Fig. 4. Warner–Bratzler shear press values for the individual subsets measured 2 days post mortem. Dots indicate 5/95 percentile for each subset.

observed by Byrne et al. (1998). One obvious reason could be that the subsets have a lower number of samples, which increases the risk for overfitted and non-robust predictive models. Examination of tenderness level in the individual subsets, showed that average WB shear press values varied very much between the sample sets (Fig. 4). Pooled standard deviations for the individual subsets were in the range 5.5 to 11.9, with average value 8.5. The pooled standard deviation, which indicate the spread of the parallels, seemed to be higher for subsets collected in the summer period compared with the other. However, the difference was not significant. There were made separate models for those samples which had low standard deviation (<5.5), but no improvement in prediction result was observed. It seems like a high average WB value was connected with high standard error. It was interesting to note that the loins were significantly more tender in the cold period of the year. This agrees with recent results on tenderness in red deer in New Zealand (Dobbie, Speck, Singh & Bass, 1997). In deer the seasonal changes in tenderness seemed to be correlated to activity of the calpain enzyme system in the muscles. To investigate whether the seasonal variation influenced the prediction results in study 1, all samples from 48 carcasses in study 2 were collected during 3 consecutive days.

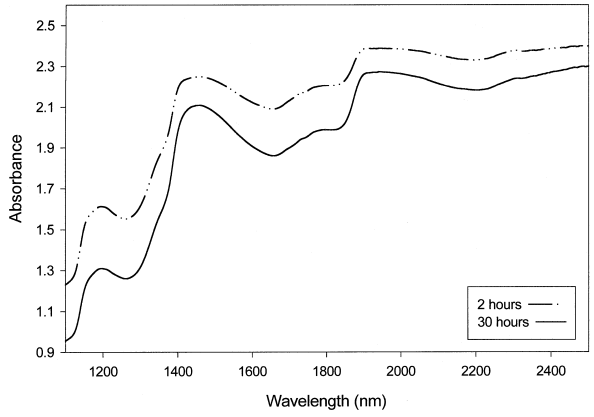

Fig. 5. Average NIR spectra measured 2 and 30 h post mortem for study 2.

Table 3
Prediction of WB shear press values from NIR reflectance spectra of study 2[a]

n	X-matrix	Y-matrix	Correlation coefficient	RMSEP	Optimal no. of factors
Without MSC					
48	NIR 2 h	WB 2 days	0.36	19.8	5
48	NIR 2 h	WB 7 days	–	–	–
48	NIR 30 h	WB 2 days	–	–	–
48	NIR 30 h	WB 7 days	–	–	–
With MSC					
48	NIR 2 h	WB 2 days	0.43	19.5	14
48	NIR 2 h	WB 7 days	0.45	15.5	10
48	NIR 30 h	WB 2 days	0.25	19.8	1
48	NIR 30 h	WB 7 days	–	–	–

[a] Partial least square regression, full cross validation (— when $r<0.20$).

3.3. Study 2. Sample set collected over 3 days (n = 48)

3.3.1. Observations on NIR spectra

The average NIR spectra (2 and 30 h post mortem) of the 48 samples are shown in Fig. 5. Compared to study 1, the overall NIR absorbances seemed to be slightly lower. The most apparent difference between the studies was seen in the 1900–2500 nm region. In study 1 the NIR signals in this region of the 4 and 26 h raw spectra were very similar, while they were clearly different in this study. The differences in average absorbances could be due to systematic differences in the experimental conditions or being a result of natural variation between the carcasses.

3.3.2. Prediction of WB shear press from NIR spectra

The prediction results of study 2 are shown in Table 3. Correlation coefficients of different prediction models were low and variable, and the RMSEP were high. MSC of NIR spectra improved the models slightly. Separate models were made for groups of electrically stimulated and not electrically stimulated carcasses (Table 4). However, the prediction models still yielded variable correlation coefficients and prediction errors.

Table 4
Prediction of WB shear press values from MSC treated NIR reflectance spectra of study 2[a]

n	X-matrix	Y-matrix	Correlation coefficient	RMSEP	Optimal no. of factors
Without ES					
24	NIR 2 h	WB 2 days	–	–	–
24	NIR 2 h	WB 7 days	–	–	–
24	NIR 30 h	WB 2 days	0.44	19.1	1
24	NIR 30 h	WB 7 days	–	–	–
With ES					
24	NIR 2 h	WB 2 days	0.62	15.1	3
24	NIR 2 h	WB 7 days	0.23	15.0	1
24	NIR 30 h	WB 2 days	0.43	17.9	3
24	NIR 30 h	WB 7 days	–	–	–
Bulls					
24	NIR 2 h	WB 2 days	0.58	20.5	7
24	NIR 2 h	WB 7 days	0.59	16.9	4
24	NIR 30 h	WB 2 days	–	–	–
24	NIR 30 h	WB 7 days	–	–	–
Cows					
24	NIR 2 h	WB 2 days	0.55	14.1	9
24	NIR 2 h	WB 7 days	0.35	11.6	5
24	NIR 30 h	WB 2 days	–	–	–
24	NIR 30 h	WB 7 days	0.22	11.9	2

[a] Partial least square regression, full cross validation (– when $r<0.20$).

Another criterion for subgroup classification was gender. Again the prediction results were not satisfactory. Further separation of samples into subsets like "ES-bulls", "NS-bulls" and so on, gave no better models.

3.4. Studies 1 and 2 pooled (n = 127)

3.4.1. Prediction of WB shear press from NIR measurements

The prediction results when combining samples from the two studies are shown in Table 5. NIR recordings after 2 and 4 h were pooled together and regarded as pre rigor samples and similarly were 26 and 30 h spectra regarded as post rigor samples. The correlation coefficients were in the range 0.47–0.55. There were no increases in the correlation coefficients when MSC was applied.

3.4.2. Prediction of intramuscular fat content from NIR measurements

Few attempts have been made to measure intramuscular fat content in intact meat by NIR. Table 6 shows the prediction results for intramuscular fat for the different sample sets. Based on 4 or 26 h NIR measurements, similar prediction results were obtained for the separate studies and the combined study, with correlation coefficients between 0.76 and 0.84 and RMSEP between 1.0 and 1.5%. Fig. 6 shows predicted fat content versus the measured value for the model where post rigor spectra were used, with 127 carcass samples. The Y-residual variance plot (Fig 7) shows a steady decrease for the first four factors, which explained 65% of the variation in fat concentration.

The major absorbance wavelengths for fat are 1152–1248, 1376–1460, 1676–1776 and 2248–2440 nm in the infrared area. A new model was made with only these wave-length areas, but a similar result was obtained as with all wavelengths. The correlation coefficient was 0.85 with seven principal factors, and RMSEP was 1.2% for this model. This prediction result is similar to those obtained by Park, Whittaker, Miller and Hale (1994), who used ultrasound measurements for fat estimation in intact meat. They predicted intramuscular fat concentration with 90% accuracy when fat level was over 8% and with 76% accuracy when fat level was below 8%. Compared to NIR prediction of fat in ground meat (Isaksson, Milller & Næs, 1992; Lanza, 1983), the correlation coefficients are much lower for intact beef. Ground or minced meat is a relatively homogeneous mixture, which means that a single NIR-scan will probably detect the "true" composition. The intact beef samples had a very heterogeneous distribution of fat, and lower correlation coefficients are to be expected. Measurement of fat in intact meat is thus basically a sampling problem. Increasing the number of NIR scans substantially on each intact meat sample would probably have improved the prediction results for fat significantly.

Table 6
Prediction of fat content from NIR reflectance spectra[a]

	n	X-matrix	Correlation coefficient	RMSEP	Optimal no. of factors
Study 1					
	79	NIR 4 h	0.78	1.5	4
	79	NIR 26 h	0.76	1.5	4
Study 2					
	48	NIR 2 h	0.76	1.3	4
	48	NIR 30 h	0.84	1.1	3
All samples					
	127	NIR pre rigor	0.78	1.4	3
	127	NIR post rigor	0.80	1.3	4

[a] Partial least square regression, full cross validation.

Table 5
Prediction of WB shear press values from NIR reflectance spectra of all samples[a]

	n	X-matrix	Y-matrix	Correlation coefficient	RMSEP	Optimal no. of factors
Without MSC						
	127	NIR pre rigor	WB 2 days	0.47	18.1	5
	127	NIR pre rigor	WB 7 days	0.51	15.3	11
	127	NIR post rigor	WB 2 days	0.55	17.5	11
	127	NIR post rigor	WB 7 days	0.54	14.9	14
With MSC						
	127	NIR pre rigor	WB 2 days	0.44	18.5	19
	127	NIR pre rigor	WB 7 days	0.45	15.8	16
	127	NIR post rigor	WB 2 days	0.54	17.7	25
	127	NIR post rigor	WB 7 days	0.48	15.7	17

[a] Partial least square regression, full cross validation.

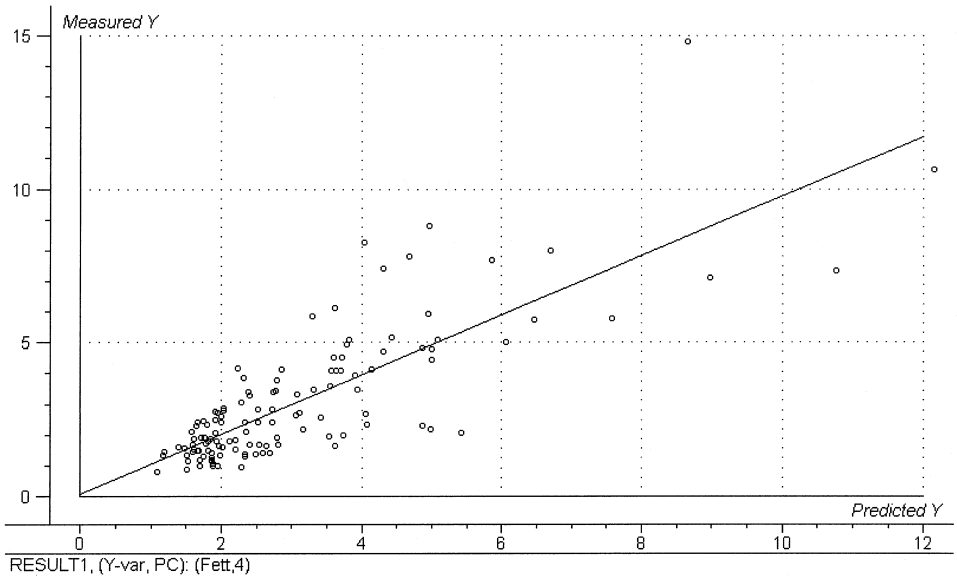

Fig. 6. Predicted fat content versus the measured value of the regression between NIR spectra recorded post rigor for all samples and measured fat content.

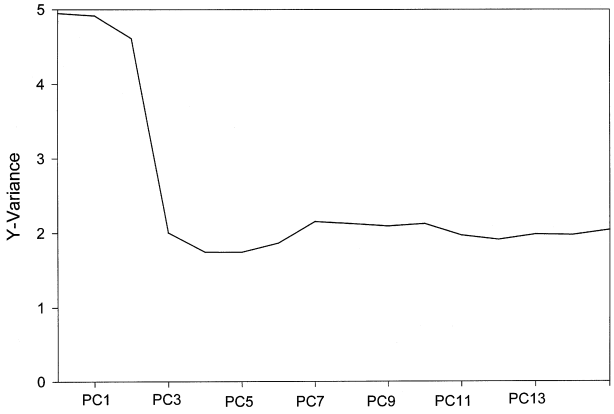

Fig. 7. Residual variance plot of the regression between NIR spectra recorded post rigor for all samples and measured fat content.

4. Conclusion

NIR spectra recorded pre rigor had overall higher absorbance compared with NIR spectra recorded post rigor in bovine *Longissimus dorsi* muscles from 127 carcasses of both bulls and cows, where 36 had been low voltage electrically stimulated. Prediction of tenderness from NIR spectra recorded pre or post rigor gave multivariate correlation coefficients up to 0.68 when WB measurements were used as response variable. Sensory analysis was performed on samples from two subsets. The correlation coefficients between these results and NIR spectra were also relatively low, 0.34–0.51. Results obtained in this study do not support that early post mortem NIR spectroscopy can be used as predictor of final tenderness. However, only wavelengths between 1100 and 2500 nm were used in this study. By including wavelengths from 750 to 2500 nm it might be possible to improve the prediction models. Prediction of fat content from early post mortem NIR spectra had higher correlation coefficients ($r = 0.76$–0.84).

Acknowledgements

The authors appreciate the valuable contributions from colleagues at MATFORSK. This study was partly funded by FAIR-project: PL961107. The prediction of meat quality at an early post mortem period by detection of novel physical and chemical markers.

References

Bendall, J. R. (1973). Postmortem changes in muscle. In *The structure and function of muscle*, (Bourne, G. H.) (Vol. 2) (pp. 243–309). Academic Press, New York.

Bjarnø, O. C. (1982). Multicomponent analysis of meat products by infrared spectrophotometry: Collaborative study. *Journal of the Association of Official Analytical Chemists*, *65*, 696–700.

Boleman, S. J., Boleman, S. L., Miller, R. K., Taylor, J. F., Cross, H. R., Wheeler, T. L., Koohmaraie, M., Shackelford, S. D., Miller, M. F., West, R. L., Johnson, D. D., & Savell, J. W. (1997). Consumer evaluation of beef of known categories of tenderness. *Journal of Animal Science, 75*, 1521–1524.

Boleman, S. J., Miller, R. K., Buyck, M. J., Cross, H. R., & Savell, J. W. (1996). Influence of realismentation of mature cows on maturity, color, collagen solubility, and sensory characteristics. *Journal of Animal Science, 74*, 2187–2194.

Byrne, C. E., Downey, G., Troy, D. J., & Buckley, D. J. (1998). Non-destructive prediction of selected quality attributes of beef by near-infrared reflectance spectroscopy between 750 and 1098 nm. *Meat Science, 49*, 399–409.

Dobbie, P., Speck, P., Singh, K., & Bass, J. (1997) In *43rd ICoMST 1997* (pp. 276–277), Auckland, New Zealand.

Dransfield, E. (1994). Optimisation of tenderisation, ageing and tenderness. *Meat Science, 36*, 105–121.

Gif, P., Tournayre, P., & Culioli, J. (1995). Automatisation d'un banc de mesure de la longueur des sarcomeres de la viande par diffraction d'une lumiere coherente (laser). *Viandes Prod. Carnes, 16*, 39–45.

Hildrum, K. I., Isaksson, T., Næs, T., Nilsen, B. N., Rødbotten, M., & Lea, P. (1995). Near infrared reflectance spectroscopy in the prediction of sensory properties of beef. *Journal of Near Infrared Spectroscopy, 3*, 81–87.

Hildrum, K. I., Nilsen, B. N., Mielnik, M., & Næs, T. (1994). 0Prediction of sensory characteristics of beef by near-infrared spectroscopy. *Meat Science, 38*, 67–80.

Isaksson, T., Miller, C. E., & Næs, T (1992). Nondestructive NIR and NIT Determination of protein, fat, and water in plastic-wrapped, homogenized meat. *Applied Spectroscopy, 46*, 1685–1694.

Isaksson, T., & Næs, T. (1988). The effect of multiplicative scatter correction (MSC) and linearity improvement in NIR spectroscopy. *Applied Spectroscopy, 42*, 1273–1284.

Jeremiah, L. E., Tong, A. K. W., & Gibson, L. L. (1991). The usefulness of muscle color and pH for segregating beef carcasses into tenderness groups. *Meat Science, 30*, 97–114.

Jones, B. K., & Tatum, J. D. (1994). Predictors of beef tenderness among carcasses produced under commercial conditions. *Journal of Animal Science, 72*, 1492–1501.

Kruggel, W. G., Field, R. A., Riley, M. L., Radloff, H. D., & Horton, K. M. (1981). Near-infrared reflectance determination of fat, protein, and moisture in fresh meat. *Journal of the Association of Official Analytical Chemistry, 64*, 692–696.

Lanza, E. (1983). Determination of moisture, protein, fat, and calories in raw pork and beef by near infrared spectroscopy. *Journal of Food Science, 48*, 471–474.

Lochner, J. V., Kauffman, R. G., & Marsh, B. B. (1980). Early-postmortem cooling rate and beef tenderness. *Meat Science, 4*, 227–241.

Martens, H., & Næs, T. (1989). *Multivariate calibration*. Chichester: John Wiley & Sons.

May, S. G., Dolezal, H. G., Gill, D. R., Ray, F. K., & Buchanan, D. S. (1992). Effects of Day Fed, Carcass Grade Traits, and Subcutaneous Fat Removal on Postmortem Muscle Characteristics and Beef Palatability. *Journal of Animal Science, 70*, 444–453.

Mitsumoto, M., Maeda, S., Mitsuhashi, T., & Ozawa, S. (1991). Near-infrared spectroscopy determination of physical and chemical characteristics in beef cuts. *Journal of Food Science, 56*, 1493–1496.

Morgan, J. B., Savell, J. W., Hale, D. S., Miller, R. K., Griffin, D. B., Cross, H. R., & Shackelford, S. D. (1991). National beef tenderness survey. *Journal of Animal Science, 69*, 3274–3283.

O'Halloran, G. R., Troy, D. J., Buckley, D. J., & Reville, W. J. (1997). The role of endogenous proteases in the tenderisation of fast glycolysing muscle. *Meat Science, 47*, 187–210.

Park, B., Chen, Y. R., Hruschka, W. R., Shackelford, S. D., & Koohmaraie, M. (1998). Near-infrared reflectance analysis for predicting beef longissimus tenderness. *Journal of Animal Science, 76*, 2115–2120.

Park, B., Whittaker, A. D., Miller, R. K., & Hale, D. S. (1994). Predicting intramuscular fat in beef longissimus muscle from speed of sound. *Journal of Animal Science, 72*, 109–116.

Shackelford, S. D., Koohmaraie, M., & Savell, J. W. (1993). Evaluation of longissimus muscle pH at three hours postmortem as a predictor of beef tenderness. *Journal of Animal Science, 71*, 51.

Shackelford, S. D., Koohmaraie, M., Wheeler, T. L., Cundiff, L. V., & Dikeman, M. E. (1994). Effect of biological type of cattle on the incidence of the dark, firm, and dry condition in the longissimus muscle. *Journal of Animal Science, 72*, 337–343.

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1995). Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* Cattle. *Journal of Animal Science, 73*, 3333–3340.

Shorthose, W. R., & Harris, P. V. (1990). Effect of animal age on the tenderness of selected beef muscles. *Journal of Food Science, 55*, 1–8.

Smulders, F. J. M., Marsh, B. B., Swartz, D. R., Russell, R. L., & Hoenecke, M. E. (1990). Beef tenderness and sarcomere length. *Meat Science, 28*, 349–363.

Wulf, D. M., O'Connor, S. F., Tatum, J. D., & Smith, G. C. (1997). Using objective measures of muscle color to predict beef longissimus tenderness. *Journal of Animal Science, 75*, 684–692.