Objectively Predicting Ultimate Quality of Post-Rigor Pork Musculature: I. Initial Comparison of Techniques

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ABSTRACT : A total of 290 pork loins were selected to include a wide variation of quality to investigate the quality categories into which most pork falls, selection criteria for these categories and methods to objectively assess ultimate pork quality. They were probed at 24 h postmortem (PM) for the following: A) light reflectance by Danish Meat Quality Marbling (MQM), Hennessy Grading Probe (HGP) and Sensoptic Invasive Probe (SIP); B) electrical properties by NWK LT-K21 conductivity (NLT) and Sensoptic Resistance Probe (SRP): and C) pH by NWK pH-K21 (NpH). Also, measurements of % drip loss (PDL) and filter paper wetness (FPW), color brightness (L*), ultimate pH (pHu), lipid content, subjective color (SC), firmness/wetness (SF) and marbling scores (SM) were assessed. Each loin was categorized as either pale, soft and exudative (PSE), reddish-pink, soft and exudative (RSE), reddish-pink, firm and non-exudative (RFN) or dark, firm and dry (DFD). Statistically comparing coefficients of determination (CD), the results indicated that overall, the HGP predicted quality groups slightly better than MQM (CD=71 and 62% respectively), NpH and SRP were less effective (CD= 56 and 44% respectively), and SIP and NLT had the lowest values (CD=36 and 5% respectively). Combining various independent variable did not greatly improve the variation accounted for. When the data was sorted into marbling groups based on lipid content, this was not accurately predicted by any of the probe measurements. The MQM probe remained the best predictor for marbling class and accounted for about 25% of the lipid content variation. This was slightly improved to 33% when pHu was combined with MQM. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 1 : 68-76*)

Key Words : Pork Quality, PSE, RSE, RFN, DFD, Marbling, Objective Prediction

INTRODUCTION

If swine producers are to be encouraged to produce pork that is desirable in quality, and if packers are to identify the postmortem (PM) variations of quality accurately, simply, quickly and economically to provide a mechanism to evaluate the quality of producer's products objectively, then it is important that procedures become available to assess quality variations. For practical reasons, it would be desirable to do this on the slaughter line at a time when weight, inspection and composition factors are measured, and when carcass identification is still intact. Unfortunately, the techniques used early PM lack accuracy for predicting ultimate pork quality for single carcass (Kauffman et al., 1993).

For the past several years, it has become obvious in the pork industry that quality is important, and that there is a genuine need to establish objective methods to identify quality variations. The survey by Kauffman et al. (1992) reflects the magnitude of this variation. The methods used to assess quality must be reasonably accurate in placing pork into a few quality groups. However, most measurement techniques produce data on a continuous scale. Therefore, cutoff criteria must be arbitrarily assigned for each attribute measured, and the quality categories must accommodate all ranges of data produced. Thus, in the present work, we studied both the quality categories in which most pork falls, and the methods used to objectively assess these categories.

For a long time it was believed that paleness, softness and exudation were always closely linked. However, there is evidence that color is not necessarily a reliable predictor of wateriness (Joo et al., 1995; van Laack et al., 1995; Warriss and Brown, 1987). Although color and water-holding capacity (WHC) are significantly related, the characteristics often vary independently. For this reason, a new quality category has been described as reddish-pink, soft and exudative (RSE) which is normal in color but still soft and exudative (Kauffman et al., 1993; Joo et al., 1995; Warner et al., 1997). Reddish-pink, firm and non-exudative (RFN) describes 'normal' or 'ideal' quality. Even though rare, additional classes also have been proposed that include pale, firm and non-exudative (PFN) (Kauffman et al., 1993), pale, firm and exudative (PFE) and pale, firm and dry (PFD)

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(Kanda and Kanechika, 1992). The conducted survey in the USA (Kauffman et al., 1992), indicated that up to one-half of the US pork supply could be RSE, having economic yield losses similar to PSE.

There is considerable literature concerning instruments used for the measurement of internal reflectance in muscle, and there is some disagreement whether electronic grading probes can be used for the detection of aberrant pork (Fortin and Raymond, 1987; Murray et al., 1989; Swatland and Irie, 1992; van der Wal et al., 1987). Borggaard et al. (1989) reported that the MQM (Meat Quality Marbling) instrument includes software for the analysis of reflectance profiles and calculates reflection values of the lean part of the profile to estimate WHC of muscle. Generally, it was recommended that r values for the prediction of WHC should be >0.9 to be of practical application. Swatland and Irie (1992) have reported the effect of wavelength on spatial measurements of light scattering and recommended the use of a red laser at 633nm for the detection of PSE pork. Andersen et al. (1993) indicated that reflectance profiles can be used to estimate intramuscular fat, pigment, collagen and protein solubility. Probes have been developed employing light reflectance (Danish Meat Quality Marbling, Hennessy Grading Probe and Sensoptic Invasive Probe), electrical conductivity (NWK LT-K21) and resistance (Sensoptic Resistance probe) as well as pH (NWK pH-K21 which includes a protective metal retractable sleeve for a durable glass electrode, and is considered to be more applicable in a packing plant environment than traditional meters and glass electrodes). Some of these instruments are currently used in slaughterhouse whereas others have yet to be considered.

Despite these observations, few published studies (Chizzolini et al., 1993; Garrido et al., 1994; Kauffman et al., 1993) have evaluated these probes, and little effort has been made to study an integrated approach to assess pork quality. Therefore, the specific objective of this study was to test and compare most available instrumentation and concepts currently considered to be applicable in predicting ultimate pork quality on a commercial basis.

MATERIALS AND METHODS

Over a period of two months (eight trials), 290 pork loins were selected to include a wide variation of quality. The four quality groups were preliminary selected based on ultimate pH (pHu), WHC (filter paper test) (Kauffman et al., 1986), and, subjective color and firmness/wetness scores (NPPC, 1991) of the longissimus thoracis et lumborum (LTL). Furthermore, for the selected RFN loins, five degrees of marbling (NPPC, 1991) were selected. It was the intention to select loins that potentially represented a broad range of quality to ensure that the samples would provide opportunity to adequately test the instrumentation available for the study.

At 24 h PM, each pre-selected loin was removed from the fabrication line and simultaneously probed at specified anatomical sites along the caudal portion of the loin for the following: A) light reflectance by Danish Meat Quality Marbling (MQM), Hennessy Grading Probe (HGP) and Sensoptic Invasive Probe (SIP) (The colormet instrument would have been used but it was not available); B) electrical properties by NWK LT-K21 conductivity (NLT) and Sensoptic Resistance Probe (SRP); and C) pH by NWK pH-K21 (NpH). The average of duplicate readings was recorded.

For each of the 290 loins, an effort was made to maintain consistency in measuring at a similar anatomical location and to follow the same procedure for each measurement (figure 1). For most of the data collection period, the same person was assigned to make the same measurements for each loin. After invasive probe measuring, the center portion of the loin (from 10th costa to the last costa) was taken to the laboratory to assess ultimate quality.

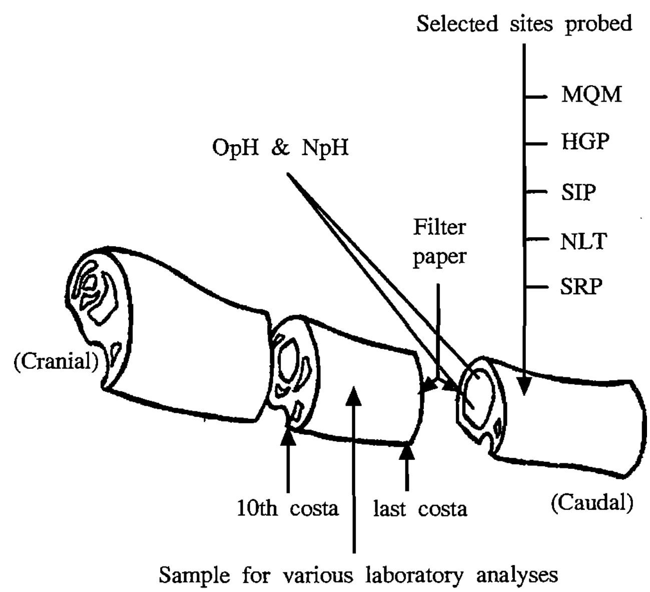

Figure 1. Anatomical locations where longissimus thoracis et lumborum was evaluated for quality. MQM=Danish Meat Quality Marbling; HGP=Henessy Grading Probe; SIP=Sensoptic Invasive Light Probe; NLT=NWK LT-K21 Conductivity Probe; SRP= Sensoptic Resistance Probe; OpH=Omega pH meter; NpH=NWK pH-K21 meter; FPW=filter paper wetness.

WHC was measured as follow: (1) 48 h percentage drip loss (PDL) by suspending duplicate muscle samples (4 cm diameter × 3 cm thick, weighing about

50 g) in an inflated plastic bag at 2℃ to measure weight loss as described by Honikel (1987), and (2) a filter paper wetness (FPW) test as described by Kauffman et al. (1986). Surface color was assessed with a Minolta Chromameter 200b (MC). Three replicate measurements were taken across the cut surface at the last costa and results were expressed as C.I.E. (Commission International de l'Eclairage) L*, a* and b*. The Chromameter used an 8 mm optic port with a glass insert and was set to D65 illuminant, 0 ° viewing angle. Four color calibration plates (No. 11133101, No. 11133853, No. 13033041, No. 16332111) were used and the auto-select option was applied. For pHu (24 h PM) duplicate measurements were made at the medial position of the last costa using an omega spear-tipped electrode connected to a pH-50 Omega portable meter (OpH). Total water content was assessed by freezing a 100 g sample of the longissimus thoracis (LT) in liquid nitrogen, powdering it in a blender and then drying it for 24 h at 105℃. Lipid content was determined by ether extraction for 48 h (AOAC, 1990).

There is sufficient evidence to believe that the most important factors of pork quality are pH, color and WHC. Therefore, pHu, L* and PDL were chosen as the main variables to use for selection criteria to assign pork into quality groups (figures 2, 3). Since they represented continuous rather than discrete variables, arbitrary limits were established. In scientific research of pork quality, the selection criteria used for assessing quality are important because they directly affect the reliability of interpreting the effectiveness of quality prediction. However, there are numerous published studies in which quality classes have been identified by pH, reflectance, conductivity and WHC individually and in combinations (Chizzolini et al., 1993; Garrido et al., 1994; Kauffman et al., 1993; Oliver et al., 1991; van der Wal et al., 1987; Warriss et al., 1991). It is possible that a sample which is not PSE pork could be labelled as PSE because it has only one of the following: low pH, pale color or low WHC. Thus, in the present study, we used more than one criteria for selection of pork quality. Initially a three-dimensional description including the arbitrary selection criteria of pHu, WHC and L* value was used to categorize four pork quality classes (figure 2). This model was then modified into a two-dimensional description using only color (L*) and WHC (PDL) (figure 3). The measure of pHu was excluded because it could not (statistically) be used both an independent and a dependent variable.

Analysis of variance was used to test differences in various traits measured for the four quality groups (SAS, 1995). Duncan's multiple range test was used to identify specific differences between individual least square means. Correlations were calculated between independent invasive measurements and the dependent ultimate quality characteristics. Simple and multiple coefficients of determination ($R^2 \times 100$, %) of the invasive measurements for predicting various ultimate quality traits were calculated.

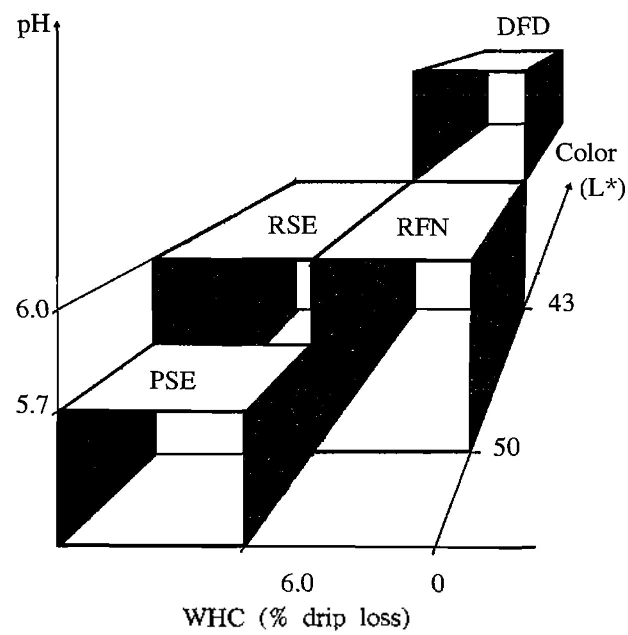

Figure 2. Using the continuous variables of ultimate pH (pHu), color (L*) and WHC (% drip loss) to identify four discrete pork quality classes

RESULTS AND DISCUSSION

Determination of criteria for pork quality

Each of the 290 loins was initially placed into one of four quality groups based on pHu, MC L* and PDL (figure 2). We then calculated means and standard deviations for each of the variables for each quality groups to confirm or reject the initial selection criteria (table 1). For example, 6% drip loss was arbitrarily chosen to separate acceptable from unacceptable WHC because it represented approximately two standard deviations less than the mean PDL of the PSE group. For color, we arbitrarily selected MC L* brightness limits that corresponded to the SC: if the MC L* value was >50, it was considered to be a minimum pale color, and if the value was ≤43, it was considered to be a minimum dark color. This explanation does not totally justify our attempt to interpret continuous variables for discrete classes, but it was an attempt to establish a few reasonably well defined quality classes that could be easily and objectively used for commerce.

It has been readily accepted that if the pHu value is ≥6.0, it is DFD. Therefore, the pHu value of 6.0

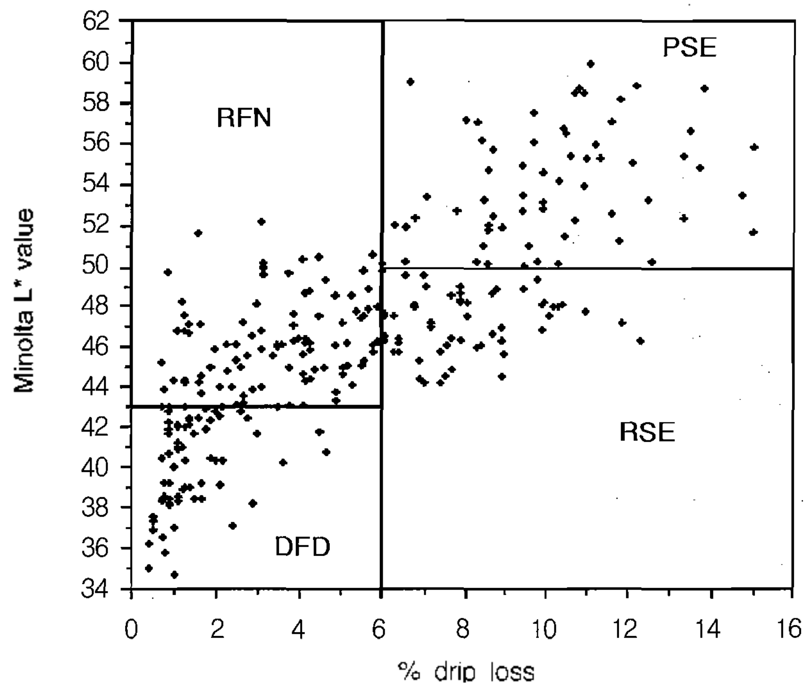

Figure 3. Distribution of 290 pork loins among four discrete quality classes based on the continuous variables of color brightness (L*) and WHC (% drip loss)

was selected to separate RFN and DFD. There is less justification to use 5.7 as the arbitrary separation between PSE and the other classes, but it seemed within reason. For the final determination of quality class as is indicated in figure 3, pHu was omitted because statistically, it should not be included as both a dependent and independent variable simultaneously.

Figure 3 includes the broad scatter of individual observations using color and PDL as the independent variables for establishing classes. Because these loins were not selected randomly, the proportions shown should not be interpreted as loins reflecting a "normal" commercial distribution.

Comparison of various techniques to predict ultimate quality

The 290 loins were identified as either PSE, RSE, RFN or DFD based on WHC and color according to the selection criteria identified in the previous section (table 1 and figure 3). All traits were significantly ($p<0.05$) different among the four quality groups except a* and b* values. As anticipated and as a part of the design, the a* and b* values were not significantly ($p>0.05$) different between RSE and RFN

Table 1. Comparison of dependent measurements[A] for each of the four quality groups (N=290)

		Ultimate quality group			
		PSE	RSE	RFN	DFD
Measurements	N	63	57	99	71
Lightness (L*)		54.2^a ±2.8	47.2^b ±1.5	46.3^c ±2.1	40.0^d ±2.2
Redness (a*)		8.3^a ±1.5	7.2^b ±1.1	7.0^b ±0.9	6.5^c ±1.0
Yellowness (b*)		7.1^a ±1.6	4.1^b ±1.4	3.8^b ±1.3	1.4^c ±1.2
Drip loss (%)		10.2^a ±2.2	8.0^b ±1.5	3.5^c ±1.5	1.4^c ±1.2
Filter paper wetness (mg)		145^a ±34	90^b ±39	45^c ±20	19^d ±16
Ultimate pH		5.41^a±0.15	5.55^b±0.14	5.46^c±0.25	6.22^d±0.33
Subjective scores[B]					
Color		1.7^a ±0.6	2.8^b ±0.4	3.0^c ±0.5	3.8^d ±0.5
Firmness/wetness		1.7^a ±0.6	2.6^b ±0.5	3.3^c ±0.5	3.9^d ±0.5
Marbling		1.9^a ±1.1	2.1^a ±1.0	3.0^b ±1.2	2.5^{ab} ±1.1

[A] Means±standard deviations; [B] Color (1=pale, 5=dark); firmness/wetness (1=soft, 5=firm); marbling (1=devoid, 5=abundant).
[a,b,c,d] Means in each row among groups having different superscript are different, $p<0.05$.

classes as was also observed by Joo et al. (1995) and Warner et al. (1997). The measurements of pHu, WHC and color were similar to those obtained by Kauffman et al. (1993), Kim et al. (1995), van Laack et al. (1995) and Warner et al. (1997).

Means and standard deviations for the various measurements for each of the four quality groups were calculated (table 2). Most of the mean values from each technique were significantly ($p<0.05$) different among PSE, RSE, RFN and DFD quality classes. However, the NLT conductivity values were not significantly ($p>0.05$) different between PSE and RSE or between RFN and DFD. Because of the clearly significant differences among quality classes, it was apparent that light reflectance (MQM, HGP, SIP), pHu (NpH) and electrical resistance (SRP) parameters were viable candidates to predict quality. The result of NLT conductivity was disappointing and were different from what was reported by Schmitten et al. (1987), Seidler et al. (1987) and Schwägele (1991). Schmitten et al. (1987) indicated that the correlation between electrical conductivity and quality at 24 h PM was higher than that between pH and quality. The NLT measurements were only weakly correlated with PDL and FPW (measurements of WHC) and even less well correlated with L*, a* and b* (measurements of color) (table 3). However, SRP values were moderately correlated with L*, PDL and OpH. These results were not expected because the two electrical properties of conductivity and resistance are related. There was only a low correlation between NLT and SRP indicating that only about 10% of the variation of one could be accounted for by the other.

Changes in conductivity of muscle have been reported to be related to abnormal quality, probably as a result of changes in membrane structure (Seidler et

Table 2. Comparison of independent invasive techniques to measure the four quality groups[A] (N=290)

		Ultimate quality group			
		PSE	RSE	RFN	DFD
Measurements[B]	N	63	57	99	71
Meat quality marbling		103^{a} ± 21	66^{b} ± 16	57^{c} ± 15	39^{d} ± 10
Hennessy grading probe		121^{a} ± 17	87^{b} ± 15	77^{c} ± 11	57^{d} ± 11
Sensoptic invasive light probe		3.52^{a} ± 0.37	3.38^{b} ± 0.33	3.31^{b} ± 0.31	2.74^{c} ± 0.27
NWK-K21 pH meter		5.47^{a} ± 0.15	5.63^{b} ± 0.14	5.80^{c} ± 0.22	6.26^{d} ± 0.32
NWK LT-L21 conductivity probe (mS)		4.9^{a} ± 0.9	4.8^{a} ± 0.7	4.4^{b} ± 1.1	4.3^{b} ± 1.2
Sensptic resistance probe (Ω)		31.2^{a} ± 7.21	40.4^{b} ± 13.9	47.7^{c} ± 19.0	71.3^{d} ± 20.4

[A] Means ± standard deviations; [B] The units for some instruments are undefinable.
[a,b,c,d] Means in each row among groups having a different superscript are different, $p<0.05$.

Table 3. Correlation coefficients between pork quality characteristics[A] (N=290)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	L*													
2	a*	0.46												
3	b*	0.88	0.70											
4	PDL	0.79	0.43	0.70										
5	FPW	0.76	0.46	0.70	0.85									
6	OpH	-0.76	-0.45	-0.70	-0.76	-0.66								
7	SC	-0.85	-0.31	-0.75	-0.76	-0.72	0.72							
8	SF	-0.82	-0.48	-0.76	-0.85	-0.82	0.76	0.82						
9	MQM	0.81	0.62	0.82	0.72	0.78	-0.68	-0.72	-0.76					
10	HGP	0.88	0.57	0.87	0.79	0.84	-0.78	-0.84	-0.86	0.92				
11	SIP	0.65	-0.40	0.48	0.55	0.47	-0.63	-0.68	-0.56	0.47	0.62			
12	NpH	-0.78	-0.44	-0.71	-0.77	-0.67	0.97	0.72	0.77	-0.69	-0.78	-0.63		
13	NLT	0.18	-0.09	0.05	0.25	0.22	-0.13	-0.16	-0.16	0.12	0.16	0.20	-0.18	
14	SRP	-0.60	-0.32	-0.52	-0.70	-0.70	0.62	0.54	0.62	-0.58	-0.64	-0.44	0.63	
15	SM	-0.18	-0.12	-0.15	-0.41	-0.40	0.31	0.25	0.44	-0.17	-0.25	-0.11	0.32	0.27

[A] PDL=% drip loss; FPW=filter paper wetness; OpH=Omega pHu value; SC=subjective color score; SF=subjective firmness/wetness score; MQM=Meat Quality Marbling; HGP=Hennessy Grading Probe; SIP=Sensoptic Invasive Light Probe; NpH=NWK pH meter (K21); NLT=NWK LT-K21 Conductivity Probe; SRP=Sensoptic Resistance Probe; SM=subjective marbling score.

All values ≥ 0.15, $p<0.01$; All values ≤ 0.10, $p<0.05$.

al., 1987). Nevertheless, our results clearly showed that the electrical properties (NLT and SRP) were related to only characteristics associated with WHC but not color, and were less related to either WHC or color when compared to other techniques. Therefore, we concluded that the detection of variations in electrical properties of post-rigor muscle could not be used to predict acceptable or unacceptable WHC. Murray et al. (1989) agreed that the Quality Meter, which is another conductivity instrument, performed less satisfactorily than other reflectance measurements for the prediction of all subjective and objective quality traits. Considerable overlap in the ranges of conductivity values associated with PSE and RFN as well as minimal differences observed between DFD and RFN were reported by Warriss et al. (1991). However, Swatland (1993) concluded that there was a clear separation between resistance and capacitance decline rates in RFN and PSE pigs under experimental conditions, but the results of electronic measurement may be no better than pH under commercial conditions, even though they are easier to measure.

As anticipated, there were significant and high ($p<0.01$) correlations between L* value and the light reflection measurements (MQM, HGP, SIP and SC). These measurements also showed highly significant ($p<0.01$) correlations with PDL, FPW and SF. The relationships were expected because the specific purpose of each of the procedures was to measure degree of color and exudate. Because color alone is not considered to be a sufficient indicator of WHC (Joo et al., 1995; Kauffman et al., 1993: van Laack et al., 1995), it would be desirable if a technique could measure both color and WHC. Although color and WHC are closely related (especially among PSE and DFD groups), unfortunately they are not perfectly related (particularly when RSE and RFN classes are compared) (Joo et al., 1995; van Laack et al., 1995). This is the specific reason why RSE pork was included in this experiment. It was anticipated that a combination of physical parameters should have improved the accuracy of predicting quality.

Coefficients of determination ($R^2\times 100$, %) of the various techniques individually and in various combinations to predict color (L*), WHC (% drip loss) and ultimate quality class were calculated (table 4). It is clearly shown that MQM and HGP performed to a higher level of accuracy than the others. The difference among the measurements of light reflectance was probably due to the different wavelengths that the measurement devices utilized. According to Swatland and Barbut (1991), visible light can be used to measure PSE pork and near-infrared wavelengths can be used to measure lipid content, pH and protein functionality for meat processing. MQM uses near-infrared monochromatic light (950 nm) whereas HGP uses visible light (560 nm). It could then be suggested that HGP would be more appropriate for detecting color and WHC, whereas MQM is better for detecting marbling. Our results showed that HGP predicted not only L* and % drip loss more accurately than MQM, but also the ultimate quality class, although there was not a large difference between the two.

Table 4. Individual and combination of independent variables related to pork quality characteristics

Individual and combination of varibles[a]	Simple and multiple coefficients of determination ($R^2\times 100$), %		
	L*	Drip loss	Overall quality[b]
NLT	3[c]	0	5
MQM	66	52	62
HGP	78	62	71
NpH	60	59	56
SRP	36	49	44
MQM+HGP	78	62	72
MQM+NpH	75	66	70
MQM+SRP	69	64	69
HGP+NpH	80	68	73
HGP+SRP	78	69	74
NpH+SRP	62	67	62
MQM+HGP+NpH	80	68	74
MQM+HGP+SRP	78	69	74
MQM+NpH+SRP	75	70	73
HGP+NpH+SRP	80	72	75
MQM+HGP+NPh+SRP	80	72	75

[a] NLT=NWK LT-K21 Conductivity Probe; MQM=Meat Quality Marbling; HGP=Hennessay Grading Probe; NpH= NWK-K21 pH meter; SRP=Sensoptic Resistance Probe.
[b] Based on a combination of L* Value and % drip loss ranges (see figure 3).
[c] All values $p<0.01$.

Comparison of various techniques to predict marbling

When only RFN samples were used in the analysis (N=99), means and standard deviations were calculated on measurements for each of the five marbling groups based on % intramuscular fat (IMF) (table 5). As anticipated, subjective marbling scores were significantly ($p<0.05$) different between each of the five marbling groups whereas most of the other measurements of color, WHC and pHu were not different. However, PDL decreased with increasing % IMF and group E had a significantly higher L* mean than other four marbling levels. From this, it was hypothesized that marbling in some way may be associated with WHC and color. Even though not documented in this report, we have observed that DFD muscles tend to contain more marbling and it is usually difficult to find DFD loins that contain minimal quantities of marbling.

Table 5. Measurements[A] for each of the five marbling groups in RFN sample (N=99)

		Marbling groups (% lipid)				
		A	B	C	D	E
		<2.0	2.0-4.0	4.0-6.0	6.0-8.0	>8.0
Measurements[B]	N	7	40	31	11	10
L*		46.2[a] ±2.2	45.5[a] ±1.8	46.2[a] ±2.0	47.0[a] ±1.8	48.8[b] ±2.4
a*		6.9[a] ±1.5	6.9[a] ±0.7	7.0[a] ±1.0	6.6[a] ±0.9	7.8[b] ±1.3
b*		4.0[a] ±1.5	3.5[a] ±1.3	3.5[a] ±1.1	4.1[a] ±0.8	5.4[b] ±1.3
PDL (%)		4.0[a] ±1.3	4.1[a] ±1.3	3.5[ab] ±1.6	2.5[bc] ±1.5	2.3[c] ±1.2
FPW (mg)		48 ±19	51 ±23	42 ±18	37 ±12	38 ±18
OpH		5.57[a] ±0.10	5.70[ab] ±0.23	5.79[bc] ±0.21	5.93[c] ±0.37	5.82[bc] ±0.19
SC		2.7[a] ±0.5	3.0[ab] ±0.5	3.1[b] ±0.5	2.9[ab] ±0.5	3.2[b] ±0.6
SF		2.9[a] ±0.3	3.1[ab] ±0.5	3.4[bc] ±0.4	3.7[c] ±0.4	3.5[c] ±0.7
SM		1.4[a] ±0.6	2.1[b] ±0.8	3.5[c] ±1.6	4.2[d] ±0.6	4.7[e] ±0.5

[A] Means ± standard deviations.
[B] PDL=% drip loss; FPW=filter paper wetness; OpH=Omega pHu value; SC=subjective color score (1=pale, 5=dark); SF= subjective firmness/wetness score (1=soft, 5=firm); SM=subjective marbling score (1=devoid, 5=abundant).
[a,b,c,d] Means in each row among groups having different superscripts are different, $p<0.05$.

Table 6. Estimated values[A] by various instrumentation for the five marbling groups in RFN samples (N=99)

	Marbling groups (% lipid)				
	A	B	C	D	E
Measurements[B]	<2.0	2.0-4.0	4.0-6.0	6.0-8.0	>8.0
MQM1	52[a] ±11	52[a] ±9	60[a] ±18	54[a] ±11	73[b] ±23
MQM2	2.2[ab] ±0.6	2.6[ab] ±0.7	3.0[b] ±0.7	3.7[c] ±0.8	4.0[c] ±1.1
HGP1	79[ab] ±6	76[a] ±10	74[a] ±9	79[ab] ±11	87[b] ±18
HGP2	88[a] ±30	75[a] ±21	84[a] ±18	111[b] ±26	113[b] ±33
SIP	3.45 ±0.34	3.32 ±0.27	3.23 ±0.31	3.44 ±0.37	3.24 ±0.35
NpH	5.65[a] ±0.08	5.75[ab] ±0.23	5.84[bc] ±0.17	5.96[c] ±0.30	5.88[bc] ±0.19
NLT (mS)	4.1 ±1.3	4.4 ±1.0	4.5 ±0.9	4.5 ±1.1	4.1 ±1.4
SRP (Ω)	68b[c] ±26	55[ab] ±21	53[a] ±16	60[abc] ±19	74[c] ±16

[A] Means ± standard deviations.
[B] MQM1=reflectance of Meat Quality Marbling; MQM2=calculated % IMF by MQM; HGP1=reflectance of Hennessy Grading Probe; HGP2=variation of reflectance of HGP; SIP=Sensoptic Invasive Light Probe; NpH=NWK pH meter (K21); NLT=NWK LT-K21 Conductivity Probe; SRP=Sensoptic Resistance Probe; SM=subjective marbling score; IMF= intramuscular fat. The units for some instruments are undefinable.
[a,b,c,d] Means in each row among groups having different superscripts are different, $p<0.05$.

Means and standard deviations for measurements from the various techniques for each of the five marbling groups were calculated (table 6). The results were not satisfactory because very few of the measurements contributed significantly as predictors of marbling. MQM2 measurements accounted for about 25% of the variation in % IMF and this was slightly improved to 33% when pHu was combined with MQM2 (table 7). Generally, the means of measurements for the five marbling groups were not significantly different. Moreover, most of the correlations were extremely low and even when they were highly significant ($p<0.01$), the percentage of variation accounting for % IMF was too low to be seriously considered as practical and accurate predictors of the trait. Although the results were not satisfactory with any technique, it might be proposed that the techniques using near-infrared wavelengths are better than those using visual wavelengths for predicting marbling. This is in agreement with the reports of Birth et al. (1978), Swatland (1983) and Swatland and Barbut (1991).

We had also anticipated that some of the electrical measurements would account for variations of marbling because there is some evidence that the electrical properties are affected by fat content of meat (Swatland, 1980, 1983). However, this did not prevail, and, although SRP showed a significant correlation with SM, it was too low to be given further consideration. Since fat is a good insulator, it has been suggested that electrical current density in certain muscles might be reduced by the occurrence of extensive tracts of IMF in a fat carcass (Swatland, 1980). Nevertheless, we found that the electrical measurements at 24 h PM were not affected by IMF, perhaps as a result of the over-riding influences of exudation and the onset of rigor. If there is sufficient extracellular fluid, IMF probably could not block the flow of electrons, and if there is not much extracellular fluid, the electrons might not flow easily between muscle fibers even if there was little IMF to serve as an insulation. Swatland (1983) reported that resistivity and capacitance were increased in some samples simply due to the presence of the muscle when compared to % IMF (i.e. marbling). We observed that if a sample was extremely pale or exudative, the MQM could not accurately assess any quantity of IMF. Even when the musculature was limited to RFN, the instrumentation used in the experiment were not practically applicable to detecting distinctly differing quantities of marbling.

Table 7. Individual and combinations of independent variables related to marbling (% lipid) in RFN samples (N=99)

Individual and combination of variables[a]	Simple and multiple coefficients of determination ($R^2 \times 100$), % Marbling (% lipid)
MQM1	25[b]
MQM2	14
NpH	12
MQM2+HGP2	25
MQM2+NpH	33
HGP2+NpH	23
MQM2+HGP2+NpH	33

[a] MQM2=calculated % IMF by MQM; HGP2=variation of reflectance of HGP; NpH=NWK-K21 pH meter.

[b] All values p<0.01.

CONCLUSION

The results of this experiment indicate that in general, color and WHC of porcine post-rigor musculature can be accurately assessed by light reflectance and pH measuring probes. The Hennessy Grading Probe was the single most effective instrument, whereas measures of electrical conductivity and resistance were much less effective. None of the probes were satisfactory for differentiating between the RSE and RFN classes nor in predicting marbling content if the intent is to use them for sorting carcasses on a commercial line.

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