Evaluation of Three Pork Quality Prediction Tools Across a 48 Hours Postmortem Period

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ABSTRACT : Numerous reports have evaluated the predictive ability of carcass probes for meat quality using measurements taken early postmortem or near 24 h. The intervening time period, however, has been largely ignored. In this study, the capacity of three probes [pH, electrical conductivity (EC), and grading probe light reflectance (GP)] to predict pork longissimus muscle quality (drip and cooking losses, Warner-Bratzler shear, L*, n = 30) was evaluated at 45 min, 90 min, 3, 6, 12, 24, and 48 h postmortem. The strongest relationships were observed between cooking loss and 6 h EC and GP (R^2 = 0.66, 0.72), and L* and GP (R^2 = 0.57-0.66, 12-48 h). pH was most valuable early postmortem (R^2 = 0.63, 90 min with cooking loss). GP at 6 h most effectively (R^2 = 0.84) predicted a two factor (cooking loss+L*) meat quality index. Results emphasize the predictive value of measures taken between 3 and 12 h postmortem. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 2 : 266-272)***

Key Words : Pork Quality, Prediction, pH, Electrical Conductivity, Light Reflectance

INTRODUCTION

Recognising that conditions immediately prior to slaughter have a major influence on ultimate pork quality (Tarrant, 1989), the New Zealand Pork Industry Board implemented, in 1993, the Pork Quality Improvement Process for abattoirs. The program was designed to reduce the incidence of meat quality defects by modifying antemortem conditions. Data collected in the mid-nineties (Morel et al., 1995), however, showed that the incidences of PSE (pale, soft, exudative) and DFD (dark, firm, dry) meat from New Zealand pork carcasses were still near 30% and 7%, respectively. An effective postmortem carcass sorting system that identified such carcasses would assist in ensuring that only pork of acceptable quality reaches consumers.

Collection of direct, objective meat quality measurements cannot be conducted routinely or practically in a commercial abattoir setting without major disruptions to the flow of the processing line or destruction of portions of the carcass. Identification of carcass quality for classification purposes, therefore, requires the use of relatively non-invasive measures of various chemical and/or physical carcass characteristics. To be useful as predictors, these characteristics must have a meaningful and stable relationship to ultimate meat quality attributes. Ideally, a prediction method will be simple to apply and will provide accurate information quickly and economically (Joo et al., 2000) as soon as possible after slaughter so that effective carcass sorting can occur.

Numerous reports have discussed the use of one, or a combination of, carcass probing methods that provide measures of pH (Warriss and Brown, 1987), electrical properties (Schmitten et al., 1987; Schwägele, 1991; Warriss et al., 1991), light reflectance (by grading probe), light scattering (by fibre optic probe; Lundström et al., 1987), stiffness (by rigorometer), and marbling for the prediction of pork quality (Oliver et al., 1991; Kauffmann et al., 1993; Joo et al., 2000). Most of these reports, however, have focussed on the relationships of early postmortem (45 min) and/or ultimate (20-24 h) probe values to meat quality with little information on measures during the intervening time gap. The predictive ability of these methods, however, appears to be dependent on the postmortem time at which the probe measurements are made, although there is disagreement amongst these reports as to how soon after slaughter they can be applied for reliable categorization of meat quality (Warriss et al., 1991). Oliver et al. (1991), for example, tested a variety of prediction combinations using pH, conductivity, and light scattering and reflectance data collected at 45 min, 2 h, and 24 h postmortem, and concluded that water holding capacity of pork was best described (R^2 = 0.62) by light $\text{scattering}_{45min}$+$\text{conductivity}_{2h}$ +light reflectance_{24h}. It is possible that the best single measurement or combination of measurements for predicting pork quality includes readings that are made some time between 45 min and 20 h postmortem.

The objective of this study was to evaluate the capacity of three commercially available instruments (pH meter, electrical conductivity meter, and grading probe) to predict subsequent meat quality attributes by gathering predictive data at seven times over a two day postmortem period.

MATERIALS AND METHODS

From a commercial abattoir in New Zealand, 30 pig

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Received April 11, 2005; Accepted August 10, 2005

Table 1. Mean values, standard deviations, and minimum/maximum values for carcass characteristics, descriptive pork quality traits, and longissimus muscle temperature at various times postmortem (N = 30)

	Mean	SD	Min	Max
Carcass weight (kg)	67.56	4.77	60.90	82.10
Backfat thickness (mm)	11.13	3.00	5.00	16.00
Drip loss (%)	4.71	1.51	2.13	9.39
Cooking loss (%)	27.70	2.97	22.26	32.67
Warner-Bratzler shear force (N)	107.58	27.46	63.94	179.56
L*	44.73	3.10	39.83	51.46
a*	6.70	1.35	4.45	10.82
b*	3.38	1.23	1.53	6.43
Postmortem temperature (°C)				
45 min	37.1	1.3	33.9	39.5
90 min	31.6	2.7	24.5	35.6
3 h	23.7	2.3	18.3	27.9
6 h	12.8	2.7	7.5	16.2
12 h	3.2	0.4	2.4	3.9
24 h	2.5	0.3	2.0	3.0
48 h	2.6	0.4	1.8	3.3

carcasses (Table 1) were selected on the basis of pH at 45 min postmortem (pH_{45}), such that a range in pH_{45} (5.3 to 6.4) values was represented. Measurements of pH were made on the *Longissimus lumborum* on the right side at the P2 location (65 mm lateral to the midline of spine at the last rib) of each carcass with an Orion 230A pH meter (Orion Research Inc, Boston, MA) using temperature compensation mode and a spear-type electrode. At the time of carcass selection duplicate measurements were made in duplicate through a fresh cut made adjacent to the pH site of electrical conductivity (EC; LF Star Conductivity Probe, Ingenieurburo R. Matthaus, Pöttmes, Germany) and grading probe light reflectance (GP; GP4 Hennessey Grading Probe, Hennessey Grading Systems Auckland, New Zealand). These three measurements (pH, EC, GP) were repeated at 90 min postmortem, after which time the longissimus muscle from the right side of each carcass was removed and transported to the meat lab at Massey University for subsequent measurements of the same characteristics at 3, 6, 12, 24, and 48 h postmortem.

Additionally, several objective measurements of meat quality were made. Unless otherwise stated, all measurements were taken following the collection of 3 h postmortem probe data. To determine drip loss, a 20 mm steak was cut from each *Longissimus* muscle, weighed, and suspended by a metal hook inside an inflated polythene bag sealed around the hook with a twist tie. After storage at $2^{o}C$ for 72 h, the samples were re-weighed to determine weight loss expressed as a percentage of the starting sample weight.

Cooking loss and Warner-Bratzler shear force (WBSF) were determined by preparing two 25 mm steaks (~210 g each) from each muscle. The steaks were weighed, placed in individual polythene bags, and cooked for 90 min in a water bath maintained at 70°C. After cooking, released moisture was poured from the bags and samples were refrigerated overnight at 1-3°C. The following day, samples were patted dry with paper towelling and reweighed to determine cooking loss expressed as a percentage of raw sample weight. From each steak, six 13×13 mm samples were prepared parallel to the fibre grain and each was sheared twice on a Warner-Bratzler shear force machine with a square blade as described by Purchas and Aungsupakorn (1993).

At 24 h postmortem, instrumental colour parameters (CIE L*, a*, b*) were evaluated on a freshly prepared slice of each muscle using a Minolta ChromaMeter (CR-200, Minolta Camera Co., Ltd., Japan).

Descriptive statistics were calculated (SAS Institute Inc., 1990) for each predictive (pH, EC, GP) and descriptive (drip loss, expressible moisture, cooking loss, WBSF, colour) meat quality measure. Correlation analysis was completed (SAS Institute Inc., 1985) to determine the relationship between the descriptive and predictive measures. Simple linear and stepwise regression analyses (SAS Institute Inc., 1990) was used to assess the predictive ability of each predictive measure for the descriptive traits, as well as an overall meat quality index, at each postmortem measurement time. Only variables with $p \leq 0.05$ were included in the predictive models. Meat quality indices were calculated as cumulative deviations from the mean for each trait, relative to the standard deviation for that trait, according to:

$$\text{Index} = \frac{MQ1_i\text{-avg } MQ1}{SD_{MQ1}} + \frac{MQ2_i\text{-avg } MQ2}{SD_{MQ2}} + \ldots$$

Where MQ1, 2,… = descriptive meat quality variables, and SD = standard deviation.

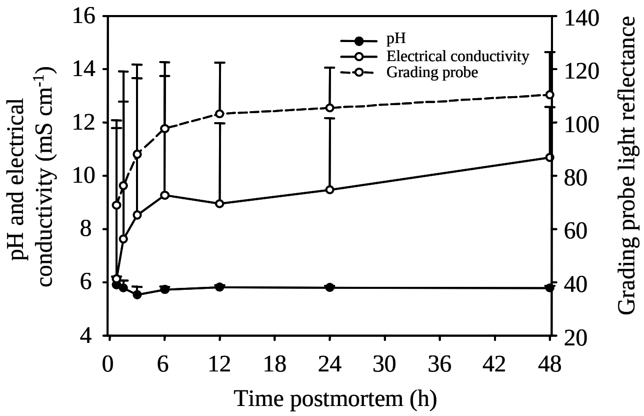

Figure 1. Postmortem changes in the predictive measurements: pH, electrical conductivity, and grading probe light reflectance. Vertical bars are standard deviations.

Table 2. Correlation coefficients amongst descriptive meat quality attributes

	CL	WBSF	L*	a*	b*
DL[1]	0.65[c]	-0.26	0.47[b]	0.37[a]	0.38[a]
CL[2]		-0.28	0.32	0.48[b]	0.29
WBSF[3]			-0.48[b]	-0.45[a]	-0.60[b]
L*				0.40[a]	0.86[c]
a*					0.68[c]

[1] DL: drip loss; [2] CL: cooking loss; [3] WBSF: Warner-Bratzler shear force.
[a] p<0.05; [b] p<0.01; [c] p<0.001.

RESULTS AND DISCUSSION

Mean descriptive meat quality and predictive probe measurements

Descriptive statistics of the descriptive meat quality attributes are listed in Table 1 and the postmortem changes in pH, EC, and GP values over time postmortem are shown in Figure 1. A characteristic early postmortem decline in pH was observed and values leveled off by 12 h at a mean near 5.8. As expected, and in agreement with previous reports, both electrical conductivity (Schmitten et al., 1987) and light reflectance as measured by the grading probe (Lundstrom et al., 1987) increased rapidly in the early postmortem period. Intact myofibres perform as electrical insulators; however, in a postmortem environment of declining pH and ATP stores, the integrity of muscle cell membranes is compromised. Membrane disruption permits a continuity of intra- and extracellular fluid, resulting in an increase in electrical conductivity (Schmitten et al., 1987). The net influx of fluid into the intercellular space may also be the cause of increased light reflectance, although the shrinkage of myofibrils with the development of rigor has also been implicated (Offer and Knight, 1988).

Correlations amongst descriptive meat quality attributes

Correlations amongst the descriptive measures (Table 2) showed a significant positive relationship between drip and cooking losses, indicating a loss of moisture from the same reservoir; that is free water from the sarcoplasm. Significant and negative correlations were noted between WBSF and each of the colour descriptors, indicating that darker meat, that tending towards DFD, produces higher shear force values as has been previously documented (Huffman and Adams, 1972; Bennett et al., 1973; Wulf et al., 2002). Conversely, a significant positive relationship was observed between drip loss and the instrumental colour parameters, thus describing, as in the PSE condition, greater moisture losses from lighter coloured meat. While van Laack et al. (1994) described a similar relationship between drip loss and L* (R^2 = 0.37, p<0.01), the relationship was biphasic, varying with pH, and L* was not considered an accurate predictor of muscles that would also be soft and exudative.

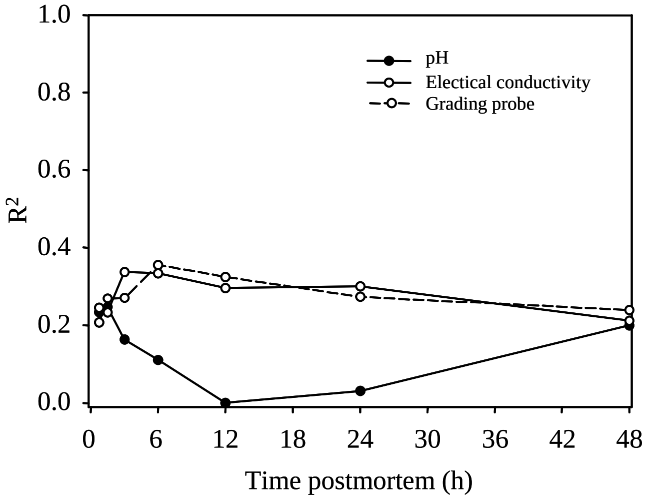

Figure 2. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for drip loss over a 48 h postmortem period.

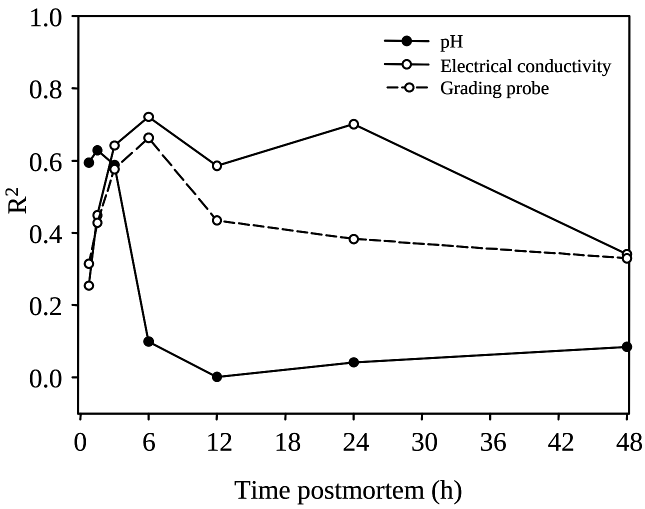

Figure 3. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for cooking loss over a 48 h postmortem period.

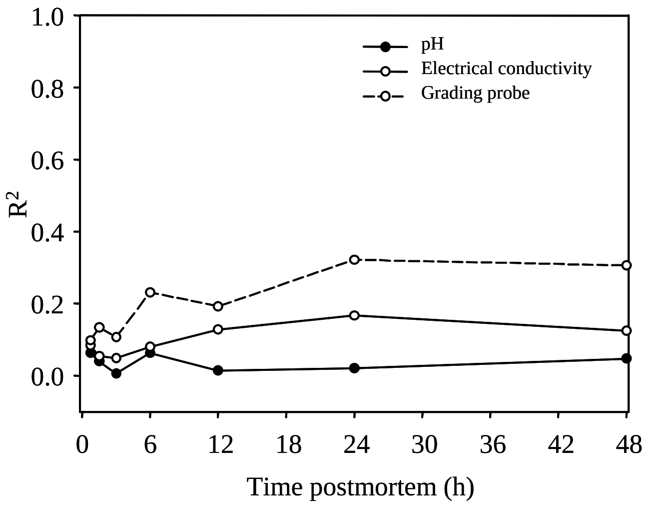

Figure 4. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for Warner-Bratzler shear over a 48 h postmortem period.

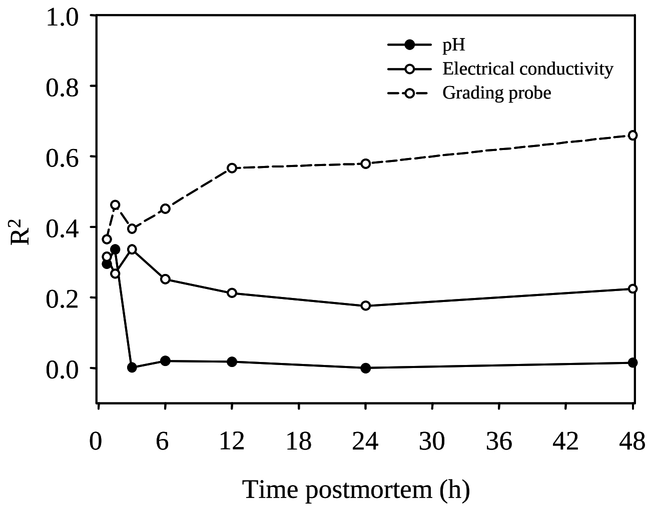

Figure 5. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for L* over a 48 h postmortem period over a 48 h postmortem period.

Prediction of meat quality measurements

The relationships between the predictive measures and individual descriptive meat quality attributes, as defined by coefficients of determination at the various postmortem measurement times, are demonstrated in Figures 2 to 5. Considerable variation in these relationships was observed, and the predictive ability of pH, EC, and GP varied with time postmortem. Drip loss was best predicted by GP at 6 h (R^2 = 0.36), while EC at 3 h gave R^2 = 0.34. In the early postmortem period, all predictive measures produced R^2 near 0.25, and by 2 d the measures had once again converged on 0.20. Oliver et al. (1991), using the Quality Meter to assess electrical conductivity, reported similar 45 min and 2 h R^2 values (0.33 and 0.42) for estimated water holding capacity, however, the relationship maintained strength to 24 h postmortem (R^2 = 0.44) rather than declining. These authors also reported a coefficient of determination of 0.44 between light reflectance at 24 h and water holding capacity.

The largest R^2 values were observed in the prediction of cooking loss. At 6 h GP and EC had R^2 values of 0.66 and 0.72, respectively, with EC peaking again at 24 h with R^2 = 0.70. While useful in the early postmortem period, the value of pH as a predictive measure declined rapidly to R^2<0.10 after a peak of 0.63 at 90 min. Prediction of WBSF was maximized at 24 and 48 h by GP with R^2 = 0.32 and 0.31, respectively. Unfortunately, none of the early postmortem measures adequately predicted subsequent instrumental tenderness with all R^2 values less than 0.15.

Prediction of L* provided relatively large R^2 values that were second only to those observed within cooking loss. Measurement of pH at 45 min was again useful with R^2 = 0.34. After an early peak of 0.46 at 90 min, GP provided R^2 values of 0.57 to 0.66 from 12 to 48 h postmortem. Joo et al. (2000) reported an R^2 of 0.78 for grading probe prediction of L* using 24 h measurements of each, far better than the predictive ability of 24 h EC readings (0.03 and 0.36) using two different conductivity meters. Interestingly, this group was able to quite successfully (R^2 = 0.60) predict L* with pH_{24} readings.

Prediction of cooking loss with pH at 90 min provided the best overall early postmortem R^2. Electrical conductivity measured at 6 h provided the highest overall R^2 with a prediction coefficient of 0.72 for cooking loss. Schmitten et al. (1987) advocated the use of EC at 40 min postmortem to predict pork quality; however, this group evaluated only two postmortem times, 40 min and 24 h. Light reflectance measurement with the grading probe provided the greatest number of high R^2 values across the descriptive measures: 0.36 at 6 h for drip loss; 0.32 and 0.31 at 24 and 48 h, respectively for WBSF; and 0.66 (48 h), 0.58 (24 h), 0.57 (12 h), and 0.46 (90 min) for L*.

While prediction of individual meat quality attributes, particularly cooking loss, by the predictive measures pH, EC, and GP, was moderately successful, there may be more value, and additional power (Kauffmann et al., 1993), in being able to predict a composite meat quality description rather than individual traits. Furthermore, Joo et al. (2000) discussed the risk of incorrect pork classification if only a single attribute was used to define quality. Meat quality is a complex issue with a definition that fluctuates across users of the term and their respective locations within the meat production and consumption chain. Attributes that may be included in the definition include colour, exudates during storage, firmness, and level of marbling (Warris and Brown, 1987; Kauffmann et al., 1993; Warner et al., 1993; Joo et al., 1995; Miller et al., 2000). Therefore, to provide a more comprehensive assessment of meat quality in the current

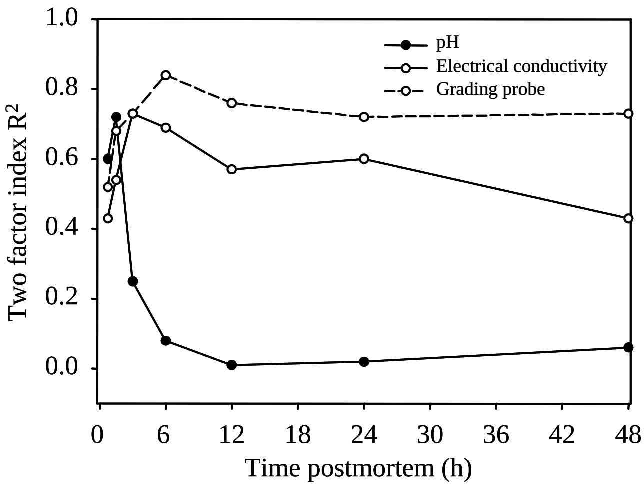

Figure 6. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for the two factor index including cooking loss and L* over a 48 h postmortem period.

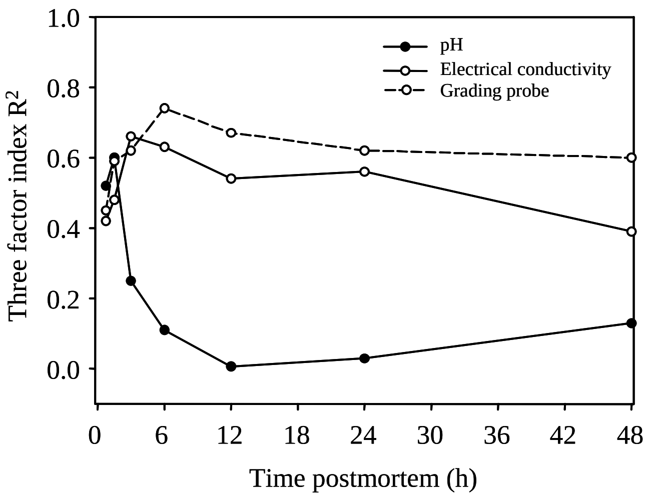

Figure 7. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for the three factor index including drip loss, cooking loss, and L* over a 48 h postmortem period.

study, several attributes were combined to produce a meat quality index.

Three indices were calculated and included various combinations of drip loss, cooking loss, WBSF, and L* but WBSF was subsequently dropped as it was relatively poorly predicted (R^2 = 0.006-0.32). Finally, a two factor index including only cooking loss and L* was calculated since these two meat quality traits were most successfully predicted on an individual basis. The R^2 values between the predictive measures and each meat quality index over the postmortem evaluation period are shown in Figures 6 through 8.

A similar pattern across time postmortem was noted amongst the R^2 values for the two and three factor indices

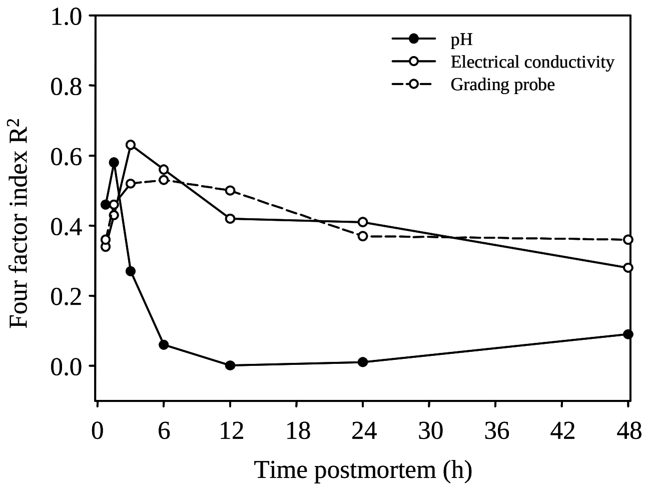

Figure 8. Coefficients of determination (R^2) of pH, electrical conductivity, and grading probe light reflectance for the four factor index including drip loss, cooking loss, Warner-Bratzler shear force, and L* over a 48 h postmortem period.

(Figures 6 and 7), with the most noticeable difference being slightly lower values for GP. Light reflectance with GP at 6 h was the best overall predictor of the two and three factor indices (R^2 = 0.84 and 0.74, respectively); however, EC at 3 h performed just as well for the two factor index (R^2 = 0.73). Joo et al. (2000) also reported good prediction of a two factor quality description (L*+drip loss) using the Hennessey grading probe (R^2 = 0.71), although the best EC relationship was described by an R^2 of only 0.44. With both GP and EC in the current experiment, there was a peak in R^2 of pH at 90 min that was similar to the predictive capacity of EC at 3 h. After 90 min, however, the predictive ability of pH dropped sharply and remained low for the remainder of the 2 d period, clearly demonstrating that ultimate pH was poor indicator of pork quality in this experiment. Oliver et al. (1991) concluded that pH measurements taken beyond the first hour postmortem were not effective quality predictors, particularly of the PSE condition. Channon et al. (2001) similarly described poor correlations pH at 48 h postmortem and sensory attributes of cooked pork (R^2 = 0.02, 0.12, and 0.03 for tenderness, juiciness, and flavour, respectively). In contrast, following their respective peaks at 3 and 6 h, EC and GP retained relatively high R^2 across the remaining measurement times, although GP outperformed EC during this extended period.

Prediction of the four factor meat quality index (Figure 8) was marked by a substantial decline in GP R^2 values that was likely due, in part, to its poor relationship to WBSF. The predictive ability of pH and its pattern over the postmortem period were consistent with the previous discussion, again with a peak at 90 min. EC also displayed an R^2 trend similar to the two and three factor indices, although the 3 h peak was slightly lower at 0.63, again, possibly lowered by a weak relationship to WBSF.

Table 3. Coefficients of determination (R^2) following stepwise regression of pH, electrical conductivity (EC), and grading probe light reflectance (GP) on each descriptive meat quality attribute and meat quality index

	Step 1		Step 2		Step 3		Model R^2	RSD
	Predictor	Partial R^2	Predictor	Partial R^2	Predictor	Partial R^2		
Cooking loss	EC 6 h	0.720	pH 90 min	0.104			0.824	1.67
Drip loss	GP 6 h	0.355					0.355	1.52
WBSF[1]	GP 24 h	0.321	EC 3 h	0.130	EC 24 h	0.082	0.534	4.08
L*	GP 48 h	0.660	pH 3 h	0.067			0.727	3.38
Four factor index (DL[2], CL[3],WBSF, L*)	EC 3 h	0.631					0.631	1.83
Three factor index (DL, CL, L*)	GP 6 h	0.741					0.741	1.57
Two factor index (CL, L*)	GP 6 h	0.839					0.839	0.439

[1] WBSF: Warner-Bratzler shear force; [2] DL: Drip loss; [3] CL: Cooking loss.

With the exception of R^2 = 0.60 for pH with the two factor index, none of the predictive measures, across all of the meat quality indices, was able to predict meat quality with an R^2 greater than about 0.45 at the very early 45 min postmortem time. Kauffman et al. (1993) also reported weak relationships (R = 0.2-0.5) between predictive measures (grading probe light reflectance, electrical conductivity, rigorometer) taken at 45 min with a variety of commercially available probes and quality measures (drip loss and L*) at 24 h. The most promising early postmortem predictor was pH_{45} with correlation coefficients of -0.5 and -0.6 with drip loss and L* (Kauffman et al., 1993). In the present study, improved predictive ability did not emerge until 90 min with pH (R^2 = 0.58-0.72), and 3-6 h with EC and GP (R^2 = 0.63-0.84).

Over all indices and times, the best single variable prediction was made on a two factor (cooking loss+L*) meat quality index using GP at 6 h postmortem (R^2 = 0.84). Little predictive ability was lost, however, by using pH at 90 min (R^2 = 0.72 for two factor index) or EC at 3 h postmortem (R^2 = 0.73 and 0.66 for 2 and 3 factor indices, respectively), or by including an additional factor (drip loss) in the index (R^2 = 0.74 with GP). Stepwise regression analysis revealed that R^2 for the prediction of drip loss and the meat quality indices was not significantly improved by the addition of further variables to the models. Cooking loss and L* prediction were strengthened by the addition of an early postmortem pH measurement, and the addition of two EC readings to a 24 h GP measurement improved the prediction of WBSF, although the R^2 was still relatively low.

IMPLICATIONS

With the exception of pH, early postmortem measurements did not maximize carcass probe predictive potential. The greatest R^2 values were between 3 and 6 h for both EC and GP, and their predictive capacity remained acceptably high to 48 h. Schmitten et al. (1987) and Warris et al. (1991) suggested later measurement times could be effective for quality control. Furthermore, carcasses late to develop PSE characteristics are difficult to detect at grading time (Lundström et al., 1987). Evaluation later postmortem increases the value of categorization efforts. The robustness of EC and GP devices vs. glass pH electrodes in abattoir conditions (Warriss et al., 1991) also makes them a good alternative. Grading probes are already in place in most operations and their additional use for quality prediction represents minimal disruption on the processing line. In practice, the best prediction tool will be one that meshes well with the logistical demands of a commercial environment. This work highlights the importance of predictive measures taken between traditional early and ultimate collection times and in combination with practical considerations could be used to guide the choice of carcass evaluation time.

ACKNOWLEDGEMENTS

We are grateful for the funding provided by the Massey University Agricultural Research Foundation.

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