RELATIONSHIP BETWEEN RATE OF pH DECLINE AND SHEAR FORCE IN LAMB

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Abstract – Meat tenderness is influenced by carcase pH and temperature decline rates *post-mortem* and attempts have been made to use these to model tenderness. Three pH/temperature carcass parameters considered influential in the relationship are pH at temperature 18°C (pH18), temperature when pH first equals 6 (Temp6), and pH at 24 hours (pH24LL). The first two of these need to be estimated for each carcass. We attempted to establish a relationship between shear force (SF) and these three pH/temperature decline variables. It also compared alternative (linear and spline based) estimates for pH18 and Temp6. Based on SF for m. *longissimus thoracis et lumborum* (LL) and m. *semimembranosus* (SM) samples collected as part of the Information Nucleus slaughter program (CRC for Sheep Industry Innovation), the study found significant relationships between SF and pH24LL, consistent across the meat cuts and ageing periods examined. However parameters pH18 and Temp6 had limited significant influence on SF.

Key Words – Lamb, Muscle, pH, Shear force, Tenderness

I. INTRODUCTION

Meat tenderness is an important eating quality trait which is affected by genetics, carcase treatment and cooking methods [1]. In particular, tenderness is dependent on background toughness (collagen level), the toughening phase (muscle contraction during rigor), and the tenderisation phase [2, 3]. The toughening phase is known to be effected by the rate of *post-mortem* glycolysis and temperature decline interactions with the extent of myofibril shortening impacting on final tenderness. This has prompted several industry recommendations in Australia, which aim to minimise sheep carcase 'cold shortening' and maximise tenderness. Processing conditions, procedures and interventions, such as electrical stimulation [4], are each focus points for these recommendations. In essence, these strive to ensure carcases reach pH 6 when carcase temperature is between 18-25°C, as this has been identified as the best range for the optimal tenderness – albeit this range has since been increased to 18-35°C [1]. This transition is often referred to as ideal pH decline or 'ideal shortening'.

Given the degree of shortening is critical to meat tenderness and eating quality, the proportion of carcases having ideal pH decline is routinely monitored and used as a quality assurance measure. This application first requires that a population of interest is defined – typically a slaughter lot on a given day and those placed in the same chiller. From this population, a sample group is monitored with resultant pH and temperature data used to estimate the proportion of carcases with ideal shortening within the population.

For the Sheep CRC slaughter program the pH decline parameters, pH at temperature 18°C (pH18) and temperature when pH first equals 6 (Temp6), were estimated for each carcass in general based on 3 pH/temperature measurements during rigor onset and a further measure at approximately 24 hours *post-mortem* (pH24LL) [5]. These data were also used to determine if carcasses were ideally shortened (i.e. 18 < Temp6 < 35). The simplest approach to determining the pH decline parameters is based on linear modelling for each carcass separately [5]. This approach has problems, not least that it leads to significantly biased estimates of the proportion of carcasses ideally shortened [6]. Random exponential modelling [6] was developed to overcome some of the

shortcomings of the linear modelling approach, but this led to new modelling problems, particularly when the pH failed to monotonically decline with declining temperature. Spline based random regression modelling [7] was subsequently developed and, at the expense of added complexity fitting the models, gives better parameter estimates. The aim of this presented research is to determine how useful pH24LL and the decline rate parameters pH18 and Temp6 are as predictors for shear force, and if useful, how do the linear and spline based estimates of pH18 and Temp6 compare as predictors.

II. MATERIALS AND METHODS

As part of the Information Nucleus for the CRC for Sheep Industry Innovation, lambs (n = 6430) representing both second cross lambs (Terminal sire x Border Leicester x Merino ewes) and first cross lambs (Terminal sire x Border Leicester or Terminal sire x Merino ewes) were slaughtered (2008-2011 drop). These lambs varied in age, up to 12 months old, and were slaughtered at commercial abattoirs following electrical (head only) stunning. All carcases were subjected to medium voltage electrical stimulation [8] and chilled at a mean temperature of 3-4°C over a 24 h period. Each carcase was trimmed to AUS-MEAT specifications [9] and then weighed (HCW) and the depth of tissue at the GR site (the depth of muscle and fat tissue from the surface of the carcase to the lateral surface of the twelfth rib 110-mm from the midline) was measured using a GR knife (GR).

The left-hand portion of the m. *longissimus thoracis et lumborum* (LL) and the caudal end over the lumber-sacral juncture were measured for pH and temperature. A section of subcutaneous fat and the m. *gluteus medius* was cut away to expose the LL and after measurement the area was resealed with overlaying tissue. pH was measured using meters with temperature compensation (WP-80, TPS Pty Ltd, Brisbane, Australia) and a polypropylene spear-type gel electrode (Ionode IJ 44), calibrated at ambient temperature. Carcase pH and temperature were measured upon entry into the chiller followed by 2 subsequent measurements as pH and temperature declined. LL pH was measured at 24 h post-mortem in the caudal site used for repeat measures following meter calibration at chiller temperatures.

The LL muscle was removed at 24 h *post-mortem* and divided into 2 portions (cranial and caudal) for shear force testing (aged for Day 1 or Day 5 respectively). Samples aged for 5 days were vacuum packed and held chilled (3-4°C) until preparation and freezing. Samples of LL were prepared into 65 g blocks and frozen (-20°C) at either 1 or 5 days of ageing for subsequent shear force (SF) testing. In a number of years samples of the m. *semimembranosus* were either aged for 1 or 5 days. All samples were cooked from frozen for 35 min in plastic bags in a water bath at 71°C [10]. Shear force was measured using a Lloyd Texture Analyser (Model LRX, Lloyd Instruments, Hampshire, UK) with a Warner-Bratzler type shear blade fitted. SF tests on samples from each slaughter group were tested at 2 separate laboratories on a randomised basis.

Regression modelling was used to predict logarithm of shear force, with the base model for each cut x ageing period given by:

$$\log(\text{Shear force}) \sim 1 + \text{LAB} + \text{HCW} + \text{GR} + \boldsymbol{FLOCK} + \boldsymbol{LOT} + \boldsymbol{ABATTOIR} + \boldsymbol{LAB{:}LOT} + \boldsymbol{LCB} + \boldsymbol{error}$$

In the model LAB corresponds to laboratory (A or B); LCB corresponds to cook batch within LAB; and terms in bold italic were fitted as random effects. To this model were added all possible combinations of the covariates given in Table 1, with each covariate, if added, added as either a linear or a quadratic model. A total of $3^5 = 243$ models were fitted for each trait, where traits are shear force for 1 and 5 day aged Loin (LL1 and LL5 respectively) and shear force for 1 and 5 day aged Topside (SM1 and SM5 respectively). The choice of optimal prediction model was based on K-fold cross validation (K = 20). For each of the K-folds (K = 20) the current model is fitted to the data excluding the k^{th} fold (k = 1, …, K), and the fitted model is used to predict the log(shear force) for the k^{th} fold given LAB, HCW, GR and covariate(s) included in the model.

Table 1. Abbreviations table describing covariates.

Covariates	Description
pH24LL	Carcase pH at 24 hours
Lin.Temp6	Linear based estimate of Temp. at pH 6
Spl.Temp6	Spline based estimate of Temp. at pH 6
Lin,pH18	Linear based estimate of pH at Temp. 18°C
Spl.pH18	Spline based estimate of pH at Temp. 18°C

For each model, the Root Mean Square Error of Prediction (RMSEP) is determined for each fold (k = 1, …, K) and from these the average and the standard error of the RMSEP across the 20 folds are determined.

For each trait (LL1, LL5, SM1 and SM5) data was restricted to records without missing values in any of the terms in the base model; any of the covariates; and the response variable. The optimal model for predicting a trait was then chosen as the simplest model (fewest terms) having average RMSEP across the K folds less than the (Average RMSEP + standard error RMSEP) for the model with the minimum average RMSEP. This model selection criterion is referred to as the one-standard-error rule [11]. Models were fitted using the package *asreml* [12] under R [13].

III. RESULTS AND DISCUSSION

For LL5, the optimal model included only a linear pH24LL effect with average RMSEP of 0.268 (Table 2) and standard error 0.003. The model with the minimum average RMSEP for LL5 included a quadratic model in pH24LL Lin.pH18 and Lin.Temp6, and had an average RMSEP of 0.266 (s.e. = 0.003) The base model for LL5 had RMSEP 0.274 (s.e = 0.003). These values are summarised in Figure 1.

This linear pH24LL effect on log(SF) is shared by each trait (Table 2) as each demonstrated increases with increasing pH24LL. This observation reflects other findings [10] where pH at 24 h post-mortem contributed more to explaining total SF variation than sarcomere length. Meat tenderness is linked to rate of pH fall [1, 14] and final pH and the latter is heavily influenced by the level of muscle glycogen at slaughter [15].

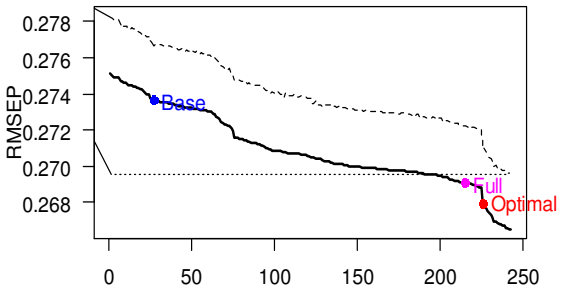

Figure 1. A plot of the average RMSEP in order of decreasing average RMSEP (solid line), and the average RMSEP plus one standard error of the average RMSEP (dashed line). Models with average RMSEP below the dotted line are contenders for an optimal model based on the one standard error rule. RMSEP for the Base, Optimal (linear pH24LL only) and Full model (including quadratic terms for all five covariates) are included.

SM5 was shown to increase not only with pH24LL, but also with increasing pH at carcase temperatures of 18°C or with decreasing temperature at pH 6, regardless of whether linear or spline model estimates were used. There was no gain to including both pH18 and Temp6 in the model, primarily due to the negative correlation between these two traits. This could relate to differences between muscles as the influence of carcase temperature at 18°C on SF was observed only in lamb topside samples. Muscle type has been shown to vary in pH level post-mortem [16] due to differences in function and subsequent activity level. Yet, based on the prevalence of pH24LL in the optimal models for estimating SF, the loin can be identified as a viable indicator of the whole carcase.

IV. CONCLUSION

pH24LL proved most useful when estimating SF in both muscles and days aged prior to SF analysis, with the SF increasing as the pH increased. And, slight differences in SF estimate precision were observed in SM aged for 5 days when using temperature at pH 6 covariates in linear models compared to spline models.

Table 2. A summary of the optimal models for each trait (LL5, LL1, SM1 and SM2) including the regression parameters (± standard error) for the pH decline covariates along with the RMSEP for the base model (null hypothesis).

Trait	Covariates in optimal model (Regression parameter ± se)	No. of samples	RMSEP (optimal model)	RMSEP (base model)
LL5	pH24 LL (0.208 ± 0.031)	4763	0.2679	0.2739
LL1	pH24 LL (0.166 ± 0.070)	887	0.2285	0.2329
SM5	pH24LL (0.374 ± 0.048) + Lin.TEMP6 (-0.0053 ± 0.0006)	3142	0.2442	0.2539
	or pH24LL (0.217 ± 0.034) + Spl.TEMP6 (-0.0077 ± 0.0007)		0.2437	
	or pH24LL (0.317 ± 0.036) + Lin.pH18 (0.223 ± 0.020)		0.2425	
	or pH24LL (0.183 ± 0.034) + Spl.pH18 (0.341 ± 0.029)		0.2426	
SM1	pH24 LL (0.357 ± 0.050)	1627	0.2158	0.2329

NOTE: These estimates are based on the full data set, excluding records with missing values. The regression parameters and the RMSEPs are for the trait on the log scale.

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