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Modelling lamb carcase pH and temperature decline parameters: Relationship to shear force and abattoir variation

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ABSTRACT

Carcase pH and temperature decline rates influence lamb tenderness; therefore pH decline parameters are beneficial when modelling tenderness. These include pH at temperature 18 °C (pH@Temp18), temperature when pH is 6 (Temp@pH6), and pH at 24 h post-mortem (pH24). This study aimed to establish a relationship between shear force (SF) as a proxy for tenderness and carcase pH decline parameters estimated using both linear and spline estimation models for the *m. longissimus lumborum* (LL). The study also compared abattoirs regarding their achievement of ideal pH decline, indicative of optimal tenderness. Based on SF measurements of LL and *m. semimembranosus* collected as part of the Information Nucleus slaughter programme (CRC for Sheep Industry Innovation) this study found significant relationships between tenderness and pH24LL, consistent across the meat cuts and ageing periods examined. Achievement of ideal pH decline was shown not to have significantly differed across abattoirs, although rates of pH decline varied significantly across years within abattoirs.

1. Introduction

Consumers expect Australian lamb to be tender; however this actuality depends upon processors as much as producers. Tenderness is a function of background toughening, the toughening phase and tenderisation phase (Koohmaraie, 1996). These latter two phases are the responsibility of meat processors and can be managed using electrical stimulation (Hwang, Devine, & Hopkins, 2003), variable ageing periods (Martínez-Cerezo et al., 2005), tender-stretching (Hopkins, 2004) and temperature control methods (Devine et al., 2002), all of which aim to prevent myofibril shortening through speeding up ATP depletion via glycolysis (Ferguson & Gerrard, 2014). Glycolysis is associated with increased carcase pH. Previous research has found that optimal lamb tenderness occurs when carcase pH is 6 over the carcase temperature range 18 °C and 35 °C (Thompson et al., 2005). This transition (pH 6 between temperature 18 °C and 35 °C) is often referred to as 'ideal pH decline' or 'ideal shortening', and is a focus of the Australian lamb meat industry to improve tenderness.

Abattoirs monitor ideal pH decline as a means to quality assure lamb tenderness and fulfil this as a requirement of the Meat Standards Australia (MSA) system (Anonymous, 2012). However, due to economic and practicality issues, the monitoring of each carcase is not feasible and sample carcases are instead monitored with recorded data applied to a total population, often a slaughter lot on a given day or all carcases placed within the same chiller. As part of the CRC for Sheep Industry Innovation meat quality research programme, all sampled carcases were measured for pH decline (Hopkins et al., 2011) based on 4 measurements, one of which included a pH at 24 h post-mortem (pH 24). From this information, three pH decline parameters can be generated: 1) pH at temperature 18 °C (pH@Temp18); 2) temperature when pH first equals 6 (Temp@pH6); and 3) pH at 24 h following slaughter as measured in the *m. longissimus lumborum* (pH24LL). These parameters are considered influential on ultimate tenderness (Thompson et al., 2005) and can provide estimates as to the proportion of a population having ideal pH decline (van de Ven, Pearce, & Hopkins, 2013). The accuracy of these estimates depends upon the appropriate selection of the models used to estimate the parameters.

The simplest approach to estimating ideal pH decline is based on linear modelling for each carcase individually (Pearce et al., 2010; van de Ven et al., 2013). However, this approach has problems; not least that it leads to significantly biased estimates of ideal pH decline proportions within a population (van de Ven et al., 2013). Random exponential models were developed to overcome this shortcoming, yet often failed when applied to insufficient or inappropriate data sets or when pH failed to monotomically decline with declining temperatures (van de Ven et al., 2013). Spline based random regression modelling was subsequently developed, applied and found to provide better estimates and are more versatile when modelling data which may not holistically comply with a given parametric model (van de Ven, Pearce, & Hopkins, 2014). Spline modelling, however, can contribute to increased

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modelling complexity and cautiousness is required when extrapolating beyond an observed data range (van de Ven et al., 2014).

The aim of this research was to evaluate the benefit of using estimates of Temp@pH6 and pH@Temp18 and pH24LL measurements when predicting lamb meat tenderness. Both linear and spline based estimates of these parameters are considered. A comparison between several Australian abattoirs in their proportional achievement of ideal pH decline over the experimental years was also undertaken.

2. Materials and methods

2.1. Carcases

As a component of the Australian Sheep Industry Cooperative Research Centre (Sheep CRC) Information Nucleus Flock (INF) (Mortimer et al., 2010), lambs ($n = 7863$) representing both second cross lambs (Terminal sire × Border Leicester × Merino ewes), first cross lambs (Maternal sire × Merino or Terminal sire × Merino ewes) and Merino lambs were slaughtered as 114 lots at 9 different abattoirs between 2009 and 2012 (Table 1). These lambs varied in age up to 12 months old and were slaughtered following electrical (head only) stunning. All lambs were subjected to medium voltage electrical stimulation and chilled at a mean temperature between 3 °C and 4 °C. Carcases were trimmed to AUS-MEAT specifications and then weighed to determine hot carcase weight (HCW). Individual carcases were measured for depth of tissue at the GR site—the depth of muscle and fat tissue from the carcase surface to the lateral surface of the twelfth rib at 110 mm from the midline, using a GR knife.

2.2. Measurements and sampling

Temperature and pH measurements were taken four times over the 24 h period immediately following slaughter as described by Pearce et al. (2010), the final being pH24LL. In overview, this involved measuring individual carcase pH and temperature in the left-hand portion of the *m. longissimus thoracis et lumborum* (loin: LL) at the caudal end over the lumber–sacral juncture. This was facilitated by sectioning subcutaneous fat and the *m. gluteus medius* away to expose and reseal the LL prior to and following measurement. pH was measured using metres with temperature compensation (WP-80, TPS Pty Ltd, Brisbane, AUS) and a polypropylene spear-type gel electrode (Ionode IJ 44), (re)calibrated at ambient temperatures intermittently throughout the experiment. Temperature was recorded using a stainless steel cylindrical probe attached to the pH metre. These measurements were used to estimate pH@Temp18 and Temp@pH6 and measure pH24LL values (Pearce et al., 2010).

At 24 h post-mortem, the LL was removed and divided into 2 portions (cranial and caudal) for shear force (SF) testing. All pairs of samples were vacuum packaged; aged respectively for 1 and 5 d (LL1 and LL5) in a 3–4 °C chiller; prepared into ~65 g blocks; and frozen until analysis. SF was measured at two separate laboratories (with samples randomly assigned within each slaughter group to both laboratories) using Lloyd Texture Analysers (Model LRX, Lloyd Instruments, Hampshire, UK) with Warner–Bratzler type shear blades fitted. At each laboratory, SF blocks were cooked from frozen for 35 min in plastic bags in a 71 °C water bath. In a number of experimental years, the *m. semimembranosus* (topside: SM) was also removed, sampled and tested identically to LL; being aged 1 or 5 d (SM1 and SM5, respectively). It should be noted, SM1, SM5 and LL1 samples were not measured throughout all experimental years.

Table 1
Summary statistics of abattoir slaughter lots (Lots) and achievement of ideal pH decline over all experimental years.

Abattoir	Lots (n)	Lot size		Proportion achieving ideal pH decline	
		Mean	Range (min.–max.)	Mean	Range (min.–max.)
A	23	53.0	27–69	0.37	0.00–0.99
B	2	43.0	42–44	0.50	0.00–1.00
C	13	43.0	20–86	0.63	0.00–0.96
D	2	75.0	74–76	0.56	0.36–0.76
E	10	71.1	34–88	0.45	0.00–1.00
F	13	47.0	25–77	0.64	0.42–0.82
G	15	50.4	23–89	0.13	0.00–0.72
H	16	99.3	85–110	0.32	0.00–0.88
I	20	96.2	30–134	0.69	0.00–1.00

2.3. Statistical analyses

2.3.1. Prediction of pH decline parameters

Three pH decline parameters are of interest in this paper (Temp@pH6, pH@Temp18 and pH24LL). Of these, pH24LL is measured directly whereas the first two, Temp@pH6 and pH@Temp18, are not observed directly and need to be estimated. As mentioned above, two approaches to estimating these parameters are considered. The first is a linear (L.) approach (Pearce et al., 2010) and the estimates so derived are denoted by L.Temp@pH6 and L.pH@Temp18 respectively. The second method is a spline (S.) based approach (van de Ven et al., 2014). Estimation using this approach, unlike the linear approach, draws information on pH/temperature decline from other carcases processed in the same lot. The spline based estimates are denoted by S.Temp@pH6 and S.pH@Temp18 respectively.

2.3.2. Variation in ideal pH decline across abattoirs

To examine differences in the proportion of carcases having ideal pH decline across abattoirs over time, the proportions of carcases with ideal pH decline within each slaughter lot were analysed using a generalised linear mixed model. The model had the number of ideally pH declined carcases in a lot as a binomial random variable with the probability that an individual carcase had ideal pH decline linearly related, on the logistic scale, to the sum of a fixed abattoir effect and a sum of a number of random effects. The uncorrelated random effects are terms for flock, year, lot and interaction effects for flock × abattoir, year × abattoir, and flock:year × abattoir. The model was fitted to the results for the complete INF data set ($n = 7863$) using the package *asreml* (Butler, 2009) under R (R Core Team, 2013).

2.3.3. Shear force prediction

From the total INF data, a subset was derived as per restrictions defined by lamb stage, limiting data to animals with no permanent incisors ($n = 6430$). On this subset, regression modelling was used to predict the logarithm of shear force [log(SF)], with the base model (Eq. (1); i.e. ignoring pH decline parameters) for each muscle and ageing period given by:

$$\log(\mathrm{SF}) \sim 1 + \mathrm{LAB} + \mathrm{HCW} + \mathrm{GR} + \boldsymbol{FLOCK} + \boldsymbol{LOT} + \boldsymbol{ABATTOIR} + \boldsymbol{LAB} \times \boldsymbol{LOT} + \boldsymbol{LCB} + \boldsymbol{error} \quad (1)$$

In this model LAB corresponds to laboratory (A or B) and LCB to cook batch within LAB, and the terms in bold italic were fitted as random effects. To this model were added all possible combinations of the null, linear and quadratic models for each of the three pH decline parameters: 1) covariate pH24LL; 2) linear and spline estimates of pH@Temp18 (L.pH@Temp18 and S.pH@Temp18 respectively), and 3) linear and spline estimates of Temp@pH6 (L.Temp@pH6 and S.Temp@pH6 respectively). A total of 243 ($=3^5$) models were fitted for each trait, where the traits were LL1, LL5, SM1 and SM5. The choice of optimal prediction model was based on K-fold cross validation ($K = 20$). For each of the K-folds the current model was fitted to the data excluding the k^{th} fold ($k = 1, \ldots, K$), and the fitted model was used to predict the log(SF) for the k^{th} fold given LAB, HCW, GR and the pH decline