



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

The effect of conditioning period on loin muscle tenderness in crossbred lambs with or without the Texel muscling QTL (TM-QTL)

Citation for published version:

Lambe, NR, Haresign, W, Macfarlane, J, Richardson, RI, Matika, O & Burger, L 2010, 'The effect of conditioning period on loin muscle tenderness in crossbred lambs with or without the Texel muscling QTL (TM-QTL)', *Meat Science*, vol. 85, no. 4, pp. 715-720. <https://doi.org/10.1016/j.meatsci.2010.03.029>

Digital Object Identifier (DOI):

[10.1016/j.meatsci.2010.03.029](https://doi.org/10.1016/j.meatsci.2010.03.029)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Meat Science

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.





The effect of conditioning period on loin muscle tenderness in crossbred lambs with or without the Texel muscling QTL (TM-QTL)

N.R. Lambe^{a,*}, W. Haresign^b, J. Macfarlane^a, R.I. Richardson^c, O. Matika^d, L. Bünger^a

^a Sustainable Livestock Systems Group, Scottish Agricultural College, King's Buildings, Edinburgh, EH9 3JG, UK

^b Institute of Biological, Environmental and Rural Sciences, University of Wales Aberystwyth, Llanbadarn Campus, Aberystwyth, Ceredigion SY23 3AL, UK

^c University of Bristol, Division of Farm Animal Science, Langford, Bristol, BS40 5DU, UK

^d Roslin Institute and Royal (Dick) School of Veterinary Studies, Roslin Biocentre, Midlothian, EH25 9PS, UK

ARTICLE INFO

Article history:

Received 28 October 2009

Received in revised form 5 March 2010

Accepted 10 March 2010

Keywords:

Meat eating quality

Meat quality

Muscularity

Texel

Lambs

QTL

ABSTRACT

A Texel muscling quantitative trait locus (TM-QTL) has been identified on chromosome 18, which increases loin muscling, but may also have a negative impact on mechanically-measured loin tenderness in crossbred lambs, depending on conditioning time. This study investigated the influence of a range of conditioning times (3, 5, 7 or 9 days) on the effect of TM-QTL on loin muscle tenderness. Using Texel rams heterozygous for TM-QTL, mated to non-carrier Mule ewes, heterozygous ($n = 45$) and wild-type ($n = 50$) crossbred lambs were produced. Weight of the valuable *Longissimus lumborum* muscle was higher in TM-QTL carriers than non-carriers, when compared at a fixed age (+11.5%; $P = 0.038$), with the same trend at a fixed carcass weight (+10.2%; $P = 0.064$). Toughness, measured by shear force, was significantly higher in samples from TM-QTL carriers than non-carriers, after conditioning for 3 days ($P = 0.002$), 5 days ($P = 0.003$) or 7 days ($P = 0.03$), but was not significantly different after 9 days of conditioning ($P = 0.32$). Compared to non-carrier lambs, the proportion of samples above consumer acceptability thresholds for toughness was greater in the TM-QTL carrier lambs after 3 and 5 days of conditioning, similar at 7 days, but lower at 9 days. The results suggest that the negative effect of TM-QTL on loin tenderness in crossbred lambs can be overcome by conditioning for more than 7 days. Marketing of TM-QTL carrier lambs through companies that use enhanced processing protocols could be beneficial, due to higher loin muscle weights, without negative effects on meat quality.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

The majority of slaughter lambs in the UK are from crossbred ewes mated to terminal sire breed rams. Crossbred ewes born to longwool breed sires (e.g. Bluefaced Leicester, Border Leicester) and hill breed dams (e.g. Scottish Blackface, Swaledale) produced over 32% of lambs sold for meat in 2003 (Pollott & Stone, 2006), whilst terminal sire breeds sired 71% of the slaughter population, with Texel rams mated to the largest number of ewes. Any genetic advances achieved in terminal sire breeds that affect slaughter characteristics are therefore likely to have the largest commercial impact if they are expressed in crossbred progeny.

Since the identification of a muscling quantitative trait locus (QTL) on chromosome 18 (OAR18) in Texel sheep (Walling et al., 2004), a collaborative project was set up to fully evaluate the effects of this QTL (known as TM-QTL) in purebred and crossbred lambs. Effects of TM-QTL on a range of carcass traits were investi-

gated in crossbred lambs and results showed significant increases in loin muscling at a given live or carcass weight, as measured by ultrasound, X-ray computed tomography (CT) and carcass dissection, but did not show substantial effects on muscling in other body regions (Macfarlane et al., 2009).

Leg and loin muscle samples from the same lambs were subsequently used to investigate the effects of TM-QTL on key meat quality traits, tenderness and intramuscular fat, after conditioning for at least 7 days (Lambe et al., 2010). The meat quality results, confirmed using different tenderness tests, indicated that male (castrated) lambs that were carriers of the TM-QTL had increased toughness (decreased tenderness) of the loin compared to non-carriers, as well as a decrease in intramuscular fat. However, there were no significant differences in these traits between carrier and non-carrier females, and no significant differences for the leg muscle.

Other results for tenderness of lamb and beef (e.g. Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008; Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Platter et al., 2003; Shorthose, Powell, & Harris, 1986) suggest a Warner–Bratzler shear force threshold of around 5–5.5 kgf (approximately 49–54 N), above which con-

* Correspondence to: SAC Kirkton farm, Criannlarich, West Perthshire, FK20 8RU. Tel.: +44 01838 400 524; fax: +44 01838 400 248.

E-mail address: Nicola.Lambe@sac.ac.uk (N.R. Lambe).

sumer acceptability declines. For the MIRINZ tenderometer, acceptable values of between 4 and 8 kgF (approximately 39–78.5 N) have been suggested, with those greater than 8 kgF indicating unacceptably tough meat (Jopson et al., 2001). Although the increase in mean shear force for the loin observed in the study by Lambe et al. (2010) was statistically significant, the differences reported may not be of commercial relevance, as means from each group were below these published thresholds, and so within the acceptable range. However, it was noted that there were a few TM-QTL carriers that were outliers in the tougher part of the range (shear force >8.0 kgF) and this degree of toughness is very likely to cause consumer dissatisfaction and would be of concern to retailers who are looking for a consistent product. Carcass processing protocols used in the study by Lambe et al. (2010) equate with the highest industry standard in the UK, with electrical stimulation and 7–12 days ageing. Many slaughter plants will typically age carcasses for around 3–5 days, and do not use electrical stimulation. However, reported results (Lambe et al., 2010) do not show the consequences of the more traditional commercial processing protocols on TM-QTL meat tenderness, and in particular whether the differences would then be of sufficient magnitude to be detected by consumers.

Information from basic meat science suggests that tenderness improves over time after slaughter, with 50% ageing being achieved by 3.3 d and 80% by 7.7 d (Dransfield, Jones, & MacFie, 1981). Taste panel assessments show that lamb loin samples that have been conditioned for 10 days are scored as significantly more tender than those conditioned for 5 days by trained assessors (SEERAD, 2004). However, it is unclear whether the rates of change over time would be the same for carcasses of lambs carrying TM-QTL as those from non-carriers. It is, therefore, vital to understand the effect of the TM-QTL on tenderness in lamb carcasses representing mainstream production, and also to determine the effect of ageing on TM-QTL meat quality, before it is possible to recommend selection for TM-QTL to the wider UK sheep industry.

The *Callipyge* mutation (*CLPG*), which is also found on OAR18, is associated with increased muscularity, lean yield and dressing percentage and reduced carcass fat, but has also been found to substantially increase toughness of meat and lower intramuscular fat content (Cockett et al., 1999; Duckett, Snowder, & Cockett, 2000). Loin chops from *CLPG* carrier lambs were found to be tougher than chops from non-carriers after ageing for 1, 3, 6, 12 or 24 days, although no significant differences were found in toughness of leg muscle samples. Although post-mortem ageing reduced shear force in both *CLPG* carrier and non-carrier lambs, the reduction happened more slowly and over a longer time period in the carrier lambs (Duckett, Klein, Dodson, & Snowder, 1998). Another QTL located in a similar position as TM-QTL on OAR18, termed the rib-eye muscling QTL (also known as LoinMAX or LM-QTL; Masri et al., 2010), was associated with a significant increase in loin shear force in New Zealand lambs that were QTL carriers (+1.54 kgF or 15.1 N) compared to non-carriers, when samples had been frozen immediately after slaughter (Jopson et al., 2001). However, this difference was not significant in samples that had undergone an enhanced post-slaughter regime, where the loin was chilled and aged for six weeks prior to testing. New Zealand lamb is commonly aged for extended periods of several weeks during export of chilled carcasses on ships to other countries. However, in the UK, much shorter ageing times (of 3–5 days) are common, making conditioning effects on meat quality much more important when considering lambs carrying these muscling QTL.

Since the loin is the most valuable meat cut in lamb, and the only significant differences in tenderness between TM-QTL carriers and non-carriers found to date were limited to shear force of this cut (Lambe et al., 2010), the loin was chosen to perform further tenderness tests. The objective of the current study was, therefore,

to investigate the influence of a range conditioning times, that were relevant to the UK industry, on the effect of TM-QTL on loin muscle tenderness in crossbred lambs.

2. Materials and methods

2.1. Animals and management

Female and entire male lambs were produced on the commercial farm at Aberystwyth University by mating two known TM-QTL heterozygous carrier rams to 18-month-old Mule ewes in mid- to late-October 2007. Natural mating took place in single-sire mating groups. All lambs were tagged at birth and were managed in a grass-based system of production typical of the UK lowland sector. All procedures involving animals were approved by the SAC and Aberystwyth University animal ethics committees and were performed under UK Home Office license, following the regulations of the Animals (Scientific Procedures) Act 1986.

A power calculation (Rasch, Herrendörfer, Bock, & Busch, 1978), based on the variation in shear force encountered in the previous study (standard deviation 1.35 kgF; Lambe et al., 2010), suggested that 40 lambs per genotype (heterozygous carrier and non-carrier) were sufficient to generate statistically valid data. This calculation used a value of 0.85 kgF as the smallest relevant difference between groups, which was based on data collected at the University of Bristol (A.V. Fisher, personal communication). It had been found that a taste panel difference of half a score unit in an eight point category scale for tenderness equated to approximately 0.85 kgF. To accommodate possible inter-experimental variation, a total of 45 TM-QTL carrier (C) lambs (25 males and 20 females) and 50 non-carrier (NC) lambs (32 males and 18 females) were reared to slaughter. Of these lambs, 25 were reared as singles (9 C, 16 NC) and 70 as twins (36 C, 34 NC). Lambs were sent for slaughter to an abattoir of Welsh Country Foods on Anglesey at approximately 21 weeks. Actual age at slaughter ranged from 148 to 157 days (average 152 days), resulting in carcass weights ranging from 8.2 to 21.8 kg (average 13.7 kg). Carcasses were electrically stimulated post-slaughter (ca. 4 h after slaughter).

2.2. Evaluation of shear force

Both left and right loin muscles (*Longissimus lumborum*) were dissected from all carcasses under commercial conditions 24 h after slaughter and sent in refrigerated transport to the University of Bristol for subsequent evaluation of shear force. On arrival at the laboratory, each of the two loins per animal was weighed, and then cut in half. For each genotype group (C and NC), each of the four loin sections within-animal were allocated to different conditioning treatments (3, 5, 7 or 9 days) using a rotational scheme (Fig. 1).

Once allocated to treatment, each sample was vacuum-packed, labelled with animal identification number, genotype group, conditioning time and date and was aged (at 1 °C) for the appropriate number of days for the treatment to which it was allocated. Samples were then frozen in a blast freezer for subsequent texture measurement at a later date.

Following thawing, samples were cooked (in vacuum pack bags) in water at 80 °C to an internal temperature of 78 °C (Teye et al., 2006). Samples were cooled in ice then held at 4 °C. Ten 10 × 10 × 20 mm blocks were cut from each muscle in the direction of the muscle fibres and sheared, using a TA-XT2 texture analyser (Stable Micro System, Surrey, UK) fitted with Volodkevitch-type jaws. Toughness was recorded as the force (kgF) required to shear the sample, with tougher (less tender) samples resulting in higher values. Results were averaged from a maximum of 10 sub-samples per muscle. However, some samples were not large

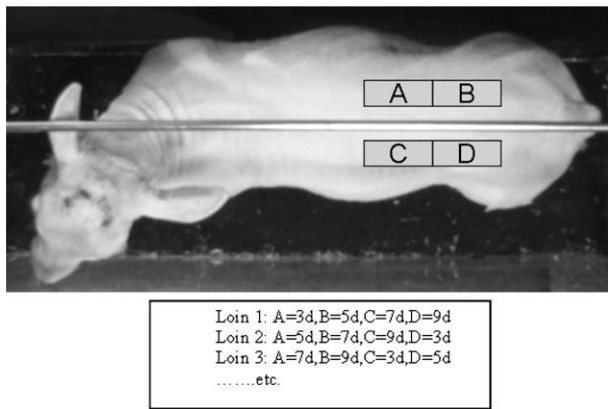


Fig. 1. Treatment allocation for loin sections.

enough to take 10 sub-samples, and in some samples results from certain sub-samples were discarded if they were obvious outliers. This resulted in the number of sub-samples ranging from 4 to 10.

2.3. Statistical analysis

Evaluation of the effects of TM-QTL status on total dissected loin muscle weight (summed from the right and left sides of the carcass) was performed fitting a general linear regression using Genstat statistical software (Payne, Murray, Harding, Baird, & Soutar, 2005). Tested in the model were the effects of slaughter age or cold carcass weight (CCW) as a covariate, and sex (entire male or female), rearing rank (single or twin), TM-QTL status (carrier or non-carrier) and all two-way interactions between these three fixed effects. Sire was not significant when fitted as a fixed effect in the model and when fitted in a mixed model as a random effect the regression analysis would not converge, so sire was dropped from the model.

The shear force data set included 380 records – four per animal, one record for each of the conditioning treatments. To assess the significance of TM-QTL status on shear force of loin muscle (ShF), general linear regression was performed using Genstat (Payne et al., 2005) to select the best fixed effects model from a maximal model including slaughter age or CCW as a covariate, sex, rearing rank, conditioning time (3, 5, 7 or 9 days), loin section (A, B, C or D), TM-QTL status and all possible two-way interactions between factors. The fixed effect model fitted was:

$$y_{ijklmno} = \mu + \text{sex}_i + \text{CT}_j + \text{LS}_k + \text{TM}_l + \text{CTLS}_m + \text{CTS}_n + \text{CTTM}_o + e_{ijklmno} \quad (1)$$

where y_{ijklm} is the shear force of loin muscle, μ is the overall mean, sex_i was the fixed effect of the sex ($i = 1, 2$), CT_j was the fixed effect of the conditioning time ($j = 3, \dots, 9$ days), LS_k was the fixed effect of loin section ($k = A, B, C, \text{ and } D$), TM_l was the fixed effect of TM-QTL status ($l = 1, 2$), CTLS_m was the interaction between conditioning time and loin section, CTS_n was the interaction between conditioning time and sex, and CTTM_o was the interaction between conditioning time and TM-QTL status, finally $e_{ijklmno}$ was the residual effect. The final model was fitted in a REML analysis and included:

$$Y = X\beta + Zu + e \quad (2)$$

where β and u are vectors of fixed effects and animal additive effects, respectively, X and Z are the incident matrices relating the data to each of these vectors, and e are residual effects. The random effects u and e were assumed normally distributed as $N(0, u\sigma_u^2)$ and $N(0, I\sigma_e^2)$, respectively.

Least-squares means were estimated for TM-QTL genotypes and for the interaction of this factor with conditioning time.

To investigate whether TM-QTL carriers were more likely to be unacceptably tough, the proportion of samples falling above the threshold of consumer acceptability (taken as 5.5 kgF, based on previous studies using Warner–Bratzler shear force, Destefanis et al., 2008; Miller et al., 2001; Platter et al., 2003; Shorthose et al., 1986) was calculated within each genotype/conditioning time group, after ShF values had been adjusted for sex and loin section. Similarly, the proportion of samples above the highest literature estimate for ShF acceptability that could be found (8 kgF using a MIRINZ tenderometer, Jopson et al., 2001) was calculated for each group, after adjustment for sex and loin section.

These adjusted shear force values were then plotted against conditioning time, within TM-QTL genotype group, and a linear regression line fitted, to investigate whether the rate of tenderisation differed between carriers and non-carriers.

3. Results

3.1. Dissected loin weights

There was a significant increase in loin weight (11.5%; $P = 0.038$) of TM-QTL carriers (least-squares mean 1.432 kg) compared to non-carriers (1.284 kg, standard error of difference (s.e.d.) 70 g) after adjusting for age and rearing rank (other fixed effects were not significant). When loin weight was adjusted for CCW, instead of age, and rearing rank, there was a 10.2% increase in TM-QTL carriers (1.423 kg) compared to non-carriers (1.291 kg, s.e.d. 70 g), which fell just below significance ($P = 0.064$).

3.2. Loin shear force

Across all ageing times, TM-QTL status had a significant effect ($P = 0.007$) on loin shear force, with carriers having significantly tougher meat than non-carriers: 6.25 vs. 5.17 kgF, s.e.d. 0.39 (61.3 vs. 50.7 N, s.e.d. 3.8 N). Shear force was significantly higher after conditioning for 3 days (6.11 kgF, 59.9 N) or 5 days (6.27 kgF, 61.5 N) than after conditioning for 7 days (5.18 kgF, 50.8 N) or 9 days (5.27 kgF, 51.7 N), across all lambs (average s.e.d. 0.20 kgF, 1.9 N). When least-squares (LS) means for the interaction between conditioning time and TM-QTL status were compared (Fig. 2), there were significant differences between carriers and non-carriers after conditioning for 3, 5 and 7 days of $P < 0.002$, $P < 0.003$ and $P < 0.03$, respectively. However, these dif-

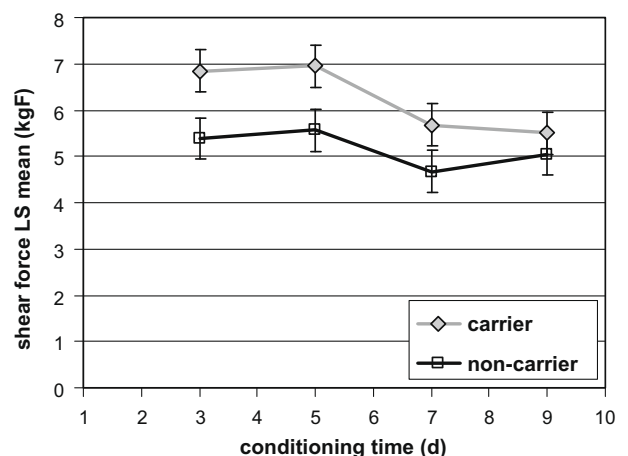


Fig. 2. The effect of conditioning time on least-squares (LS) means for shear force of loin muscle from lambs of different TM-QTL genotypes.

ferences were non-significant after 9 days of conditioning ($P = 0.32$). Within non-carriers, the only significant difference in shear force between conditioning times was between 5 and 7 days. However, within TM-QTL carriers, the shorter two conditioning times (3 and 5 d) resulted in significantly tougher meat than the longer two treatments (7 and 9 d).

Loin samples taken from the caudal end (back) of the loin, sections B and D, were significantly less tough than those from the cranial end of the loin. Samples from the same position on either side of the carcass (i.e. A vs. C; B vs. D; Fig. 1) were not significantly different to each other at any of the four time points. Least-squares means for A and C were therefore averaged at each time point, and means from B and D were averaged, to show the results in Fig. 3. Samples from the caudal end (B and D) were significantly less tough than those from the cranial end (A and C) of the loin at days 5 and 9 of conditioning.

There was no significant sex difference in toughness, except for the 5 day conditioned samples (where females were significantly tougher than males). Sex by genotype interaction, rearing rank, CCW or slaughter age did not account for significant additional variation in shear force, so were not fitted in the final model.

Raw standard deviation (s.d.) for ShF was similar for carriers and non-carriers (2.3), overall. However, at 3 d conditioning, carriers had a higher s.d. (2.45 vs. 1.90) and at 9 d conditioning carriers had a lower s.d. (1.82 vs. 2.28), although at 5 and 7 d conditioning s.d. was similar between genotypes.

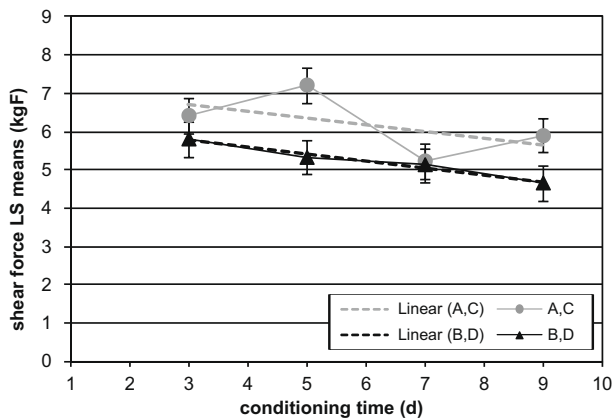


Fig. 3. The effect of conditioning time on least-squares (LS) means for shear force of muscle samples taken from the cranial (A,C) and caudal (B,D) end of the loin.

All least-squares mean values shown in Fig. 2 are above 5.5 kgF, except for the means for non-carrier samples conditioned for 7 or 9 days, implying that a significant proportion of samples were above previously-published consumer acceptability levels of toughness. The proportion of samples within each genotype/conditioning time group with ShF values above 5.5 kgF or 8 kgF (after adjusting for sex and loin section) are shown in Fig. 4a and b, respectively. After 3 days of conditioning more samples from carrier lambs than from non-carriers were above the 8 kgF threshold and at 5 days of conditioning more carrier lambs were above both threshold values. However, by day 7 of conditioning, proportions were similar between the genotypes, and by day 9 more samples from the non-carrier lambs were above both of these shear force thresholds.

A linear regression model did not fit well to the shear force data when plotted against conditioning time (Fig. 5) and explained only 19% of the variation in carrier ShF and 3% in non-carriers. From Fig. 5, it appears that this poor fit is likely to be influenced, in part, by outlying values, particularly the high values observed at day 5 of conditioning, which were mostly from non-carrier lamb samples. Although the slope of the regression line for carriers (-0.254) was more negative than that for non-carriers (-0.098), suggesting that the rate of reduction of toughness with conditioning was greater in the TM-QTL carrier samples, this difference was not significant ($P = 0.136$). However, this trend agrees with those observed in Fig. 4.

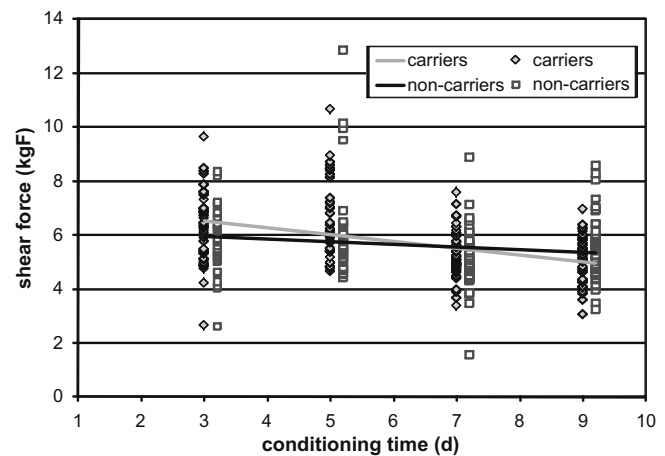


Fig. 5. Linear regression of shear force (after adjustment for sex and loin section) on conditioning time (carrier values offset by 0.2 d on X-axis to view more clearly).

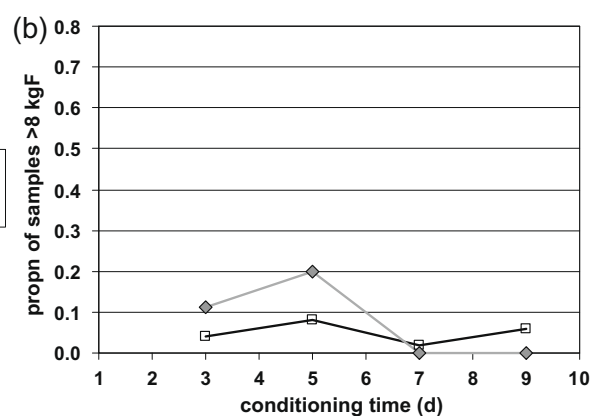
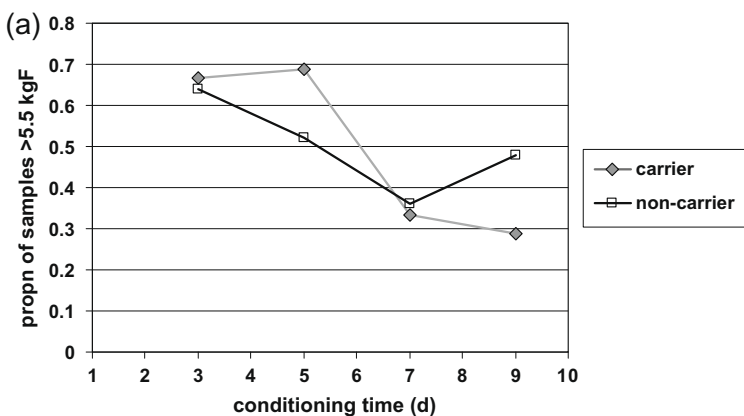


Fig. 4. Proportion of samples in each genotype/conditioning time group above acceptability thresholds of (a) 5.5 kgF and (b) 8 kgF, after adjustment for sex and loin section.

4. Discussion

The direct effect of an increase in loin weight in crossbred lambs, as a result of carrying one copy of TM-QTL (Macfarlane et al., 2009), was confirmed in this study, and the magnitude of the effect was similar (10–12% in this study and 7% in the earlier study). TM-QTL carriers also had significantly tougher loin muscles than non-carriers. However, differences between this study and the previous study that require further explanation include those related to sex by genotype interactions, magnitude of the shear force values observed and outlying values at the tough end of the range.

The sex by genotype interaction observed in the previous study was not evident here. Entire males tend to have less tender meat than castrates (Field, 1971) and so any increased toughness observed in castrated carrier lambs was expected to be greater in entire male lambs carrying TM-QTL, increasing the differential between female and males. However, this was not the case. The lambs in the current study were produced on a different farm, using a different Mule ewe flock, but one of the two TM-QTL sires used was the same across studies. The carcasses were smaller on average in the current study compared to the previous study (13.7 kg vs. 18.3 kg) when slaughtered at an average age of 21 weeks. However, carcass weight, which ranged from 8.2 to 21.8 kg, had no significant effect on ShF in the current analysis. Therefore, size or stage of maturity (expressed as a lower proportion of mature weight) cannot fully explain the differences in the effect of sex in the two studies.

Mean ShF values were higher (5.17 for non-carriers, 6.25 kgF for carriers) than those found in the previous study (2.85 for non-carriers, 3.69 kgF for carriers) when measured by the same equipment. There were also a number of samples with extremely high shear force values (61 samples >8 kgF, 20 samples >10 kgF). The reason for the increase in toughness compared to the previous trial is not clear. Lambs were slaughtered at the same abattoir in both studies, using the same electrical stimulation method. Post-slaughter processing protocols are known to have major effects on meat quality traits, such as tenderness (SEERAD, 2004). Electrical stimulation of carcasses allows more rapid chilling without cold-shortening and causes the tenderisation process to start earlier (Carse, 1973; Hwang, Devine, & Hopkins, 2003). Electrical stimulation may differentially influence young or light carcasses (Thompson, 2002). However, shear force was not related to carcass size, conformation or fatness grades (converted to numeric scales), with correlations close to zero suggesting that high shear force values were not related to stage of maturity, fatness or muscling. Unrecorded processing factors, such as electrical stimulation or chilling conditions, could have affected tenderness of all, or some of, the samples. Carcasses were slaughtered in batches of 20 and at the end of the processing line were removed to be assessed by a video image analysis system (as part of the larger trial), and only returned for electrical stimulation once all batches were measured. This resulted in differences in the time interval between slaughter and electrical stimulation. However, very high ShF values were not related to slaughter order, which makes these explanations less likely. Significant effects on tenderness of lamb and beef have been identified in previous studies due to the abattoir used or even slaughter day within-abattoir, which cannot be fully explained by factors such as method of electrical stimulation or level of finish of the animals (e.g. Hildrum, Solvang, Nilsen, Frøystein, & Berg, 1999; Johnston, Reverter, Robinson, & Ferguson, 2001; SEERAD, 2004). Differences in unmeasured effects, such as rate of cooling or storage temperatures, were thought to be possible causes for these differences. Strict protocols were followed at the University of Bristol to standardise freezing, thawing, cooking and measurement of the loin samples, and no obvious relationship was ob-

served between number of replicate sub-samples tested and high ShF values.

In the previous study (Lambe et al., 2010), the highest ShF value recorded on a non-carrier lamb was 5.9 kgF (57.9 N), whereas the highest TM-QTL carrier was 11.9 kgF (116.7 N) and the three samples measuring over 8 kgF were all from carriers. However, of the 61 samples with ShF measurements >8 kgF in the current study, 60% were TM-QTL carriers and 40% non-carriers. Outlying values in the tough end of the ShF scale were most commonly encountered in the samples that had been aged for 5 days. The reason for this is unknown and is not obviously explained by any of the variables recorded. Five day conditioning of lamb carcasses is likely to be the treatment that would be most typical in UK slaughter plants. Separate analysis of only the data from the 5 day conditioning treatment still resulted in a significant difference between ShF values of samples from carriers and non-carriers. Nevertheless, very high individual shear force values were not consistently related to TM-QTL genotype.

The tenderness-measuring equipment that was used in the present study (TA-XT2 texture analyser fitted with Volodkevitch-type jaws), uses a “bite test”, where the cooked meat sample with square cross-sectional area is compressed between two opposing rounded blades. The MIRINZ tenderometer uses a similar mechanism. However, the Warner–Bratzler equipment uses a “shear test”, where one bevelled blade with a V-shaped edge is driven into an opposing slot and through a round core of muscle (Wheeler, Shackelford, & Koohmaraie, 2010). Although all these devices measure tenderness in terms of kgF, it is not known whether the reference values used here to indicate the limits of consumer acceptability (which were measured using MIRINZ or, more commonly, Warner–Bratzler equipment) are directly comparable to values measured by the TA-XT2 device fitted with Volodkevitch jaws. Dransfield et al. (1981) commented that a 5 kgF difference using Volodkevitch jaws was equivalent to about 3 points of an 8-point sensory panel tenderness scale. Hence, a difference of 1.08 kgF, as found here between ShF least-squares means for carriers and non-carriers (6.25 vs. 5.17 kgF), would be greater than 0.5 scale points on the sensory panel scale, a difference which is often found to be highly significantly different (R.I. Richardson, personal communication).

Although found on the same chromosome, TM-QTL is known not to be due to the same mutation as *CLPG*, since this mutation was not found in the Texel sires initially used to identify the TM-QTL (S.C. Bishop, personal communication). However, it can not be fully excluded that the basis of the TM-QTL is another mutation in the same gene. Unlike *CLPG* (Duckett et al., 1998), enhanced processing eliminates the negative effects of TM-QTL on shear force tenderness. The reduction in toughness with ageing was found to be slower in *CLPG* carriers than non-carriers, but the opposite appears to be true for TM-QTL carriers vs. non-carriers within the present study, with no significant differences between groups after 9 days of conditioning. Thus, if the lambs from these carrier sires are processed through abattoirs with enhanced protocols they could benefit from increased loin weights with no detrimental effects on resulting tenderness.

The frequency of TM-QTL carriers in the UK Texel population is not currently known. Within-family linkage disequilibrium has been reported for this QTL (Macfarlane et al., 2009), which means that different marker haplotypes are associated with the TM-QTL in different sire families. This implies that a straight-forward population-wide molecular test would not be available, unless further fine-mapping results in robust markers that were in population-wide linkage disequilibrium with the causative mutation(s). The impact of the current results could have very different implications depending on the background frequency of TM-QTL in the wider

population. If this is low, then introduction of the QTL could result in a further increase in muscling in Texel-sired lambs, particularly in the high-priced loin region of the carcass. However, without enhanced processing, the tenderness of the meat resulting from these lambs may be reduced. If the current frequency of TM-QTL is high, then our results would suggest that more careful processing of all Texel crossbred lambs would lead to a marked improvement in meat quality from these genotypes.

As part of the larger study that encompasses this work, tenderness will also be assessed in purebred Texel lambs carrying zero, one or two copies of the TM-QTL. This will help to determine the mode of inheritance of the TM-QTL and test whether the effects on carcass and meat quality traits are additive. A sample of the purebred lambs produced will also be assessed by consumer panel. This will allow a clearer indication of how meat quality acceptability is associated with the TM-QTL, which will, arguably, be more relevant than thresholds implied by objective, mechanical tests of tenderness.

4.1. Implications

As found by Lambe et al. (2010), TM-QTL appears to have a negative effect on loin tenderness in crossbred lambs. This can be overcome by enhanced processing, but would require conditioning for more than 7 days. However, if crossbred lambs carrying TM-QTL were marketed through appropriate companies that use enhanced processing protocols, they could potentially lead to increased returns, resulting from higher loin muscle weights, without any negative effects on meat quality.

Acknowledgements

The authors are grateful for financial support from BBSRC (BB/E018963/1) and Defra (LK0670) for this research through LINK (Sustainable Livestock Production Programme). We thank also our industry sponsors and project partners: EBLEX, HCC, QMS, LMCNI, Catapult Genetics Pfizer, AgResearch New Zealand, Innovis Genetic Ltd., Welsh Country Foods Ltd., EplusV/Germany, ASDA stores, Scottish Association of Meat Wholesalers, Suffolk Sire Referencing Scheme Ltd., British Texel Sheep Society Ltd., and Charollais Sire Reference Scheme. Thanks go to IBERS farm and technical staff, to Amer Masri for help collecting the loin muscles and to Duncan Marriott at the University of Bristol for carrying out all the texture measurements. The authors are also grateful to members of the project Steering Committee for advice and guidance.

References

- Carse, W. A. (1973). Meat quality and acceleration of post-mortem glycolysis by electrical stimulation. *Journal of Food Technology*, 18, 163–166.
- Cockett, N. E., Jackson, S. P., Snowden, G. D., Shay, T. L., Berghmans, S., Beever, J. E., et al. (1999). The callipyge phenomenon: Evidence for unusual genetic inheritance. *Journal of Animal Science*, 77(Suppl. 2), 221–227.
- Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. *Meat Science*, 78(3), 153–156.
- Dransfield, E., Jones, R. C. D., & MacFie, H. J. H. (1981). Tenderising in *M. longissimus dorsi* of beef, veal, rabbit, lamb and pork. *Meat Science*, 5(2), 139–147.
- Duckett, S. K., Klein, T. A., Dodson, M. V., & Snowden, G. D. (1998). Tenderness of normal and callipyge lamb aged fresh or after freezing. *Meat Science*, 49(1), 19–26.
- Duckett, S. K., Snowden, G. D., & Cockett, N. E. (2000). Effect of the callipyge gene on muscle growth, calpastatin activity, and tenderness of three muscles across the growth curve. *Journal of Animal Science*, 78, 2836–2841.
- Field, R. A. (1971). Effect of castration on meat quality and quantity. *Journal of Animal Science*, 32(5), 849–858.
- Hildrum, K. I., Solvang, M., Nilsen, B. N., Frøystein, T., & Berg, J. (1999). Combined effects of chilling rate, low voltage electrical stimulation and freezing on sensory properties of bovine *M. longissimus dorsi*. *Meat Science*, 52(1), 1–7.
- Hwang, I. H., Devine, C. E., & Hopkins, D. L. (2003). The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. *Meat Science*, 65(2), 677–691.
- Johnston, D. J., Reverter, A., Robinson, D. L., & Ferguson, D. M. (2001). Sources of variation in mechanical shear force measures of tenderness in beef from tropically adapted genotypes, effects of data editing and their implications for genetic parameter estimation. *Australian Journal of Experimental Agriculture*, 41(7), 991–996.
- Jopson, N. B., Nicoll, G. B., Stevenson-Barry, J. M., Duncan, S., Greer, G. J., Bain, W. E., et al. (2001). Mode of inheritance and effects on meat quality of the rib-eye muscling (REM) QTL in sheep. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics*, 14, 111–114.
- Lambe, N. R., Macfarlane, J. M., Fisher, A. V., Matika, O., Haresign, W., & Bunger, L. (2010). The effect of a Texel Muscling QTL (TM-QTL) on meat quality traits in crossbred lambs. *Meat Science*, 85(4), 684–690.
- Macfarlane, J. M., Lambe, N. R., Bishop, S. C., Matika, O., Rius Vilarrasa, E., McLean, K. A., et al. (2009). Effects of the Texel muscling quantitative trait locus on carcass traits in crossbred lambs. *Animal*, 3, 189–199.
- Masri, A. Y., Lambe, N. R., Macfarlane, J. M., Brotherstone, S., Haresign, W., Rius Vilarrasa, E., et al. (2010). The effects of a loin muscling quantitative trait locus (LoinMAX™) on carcass and VIA-based traits in crossbred lambs. *Animal*, 4(3), 407–416.
- Miller, M. F., Carr, M. A., Ramsey, C. B., Crockett, K. L., & Hoover, L. C. (2001). Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science*, 79(12), 3062–3068.
- Payne, R. W., Murray, D. M., Harding, S. A., Baird, D. B., & Soutar, D. M. (2005). *GenStat for Windows, Introduction* (8th Ed.). Hemel, Hempstead: VSN International.
- Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science*, 81(11), 2741–2750.
- Pollott, G. E., & Stone, D. G. (2006). *The breeding structure of the British sheep industry 2003*. London: Defra.
- Rasch, D., Herrendörfer, G., Bock, J., & Busch, K. (1978). *Verfahrensbibliothek Versuchsplanung und -auswertung – Band 1 and 2*. Berlin: VEB Deutscher Landwirtschaftsverlag.
- SEERAD (2004). Factors Affecting Lamb Eating Quality. Meat Eating Quality – A Whole Chain Approach, SEERAD Report.
- Shorthose, W. R., Powell, V. H., & Harris, P. V. (1986). Influence of electrical stimulation, cooling rates and aging on the shear force values of chilled lamb. *Journal of Food Science*, 51, 889–892.
- Teye, G. A., Sheard, P. R., Whittington, F. M., Nute, G. R., Stewart, A., & Wood, J. D. (2006). Influence of dietary oils and protein level on pork quality. 1. Effects on muscle fatty acid composition, carcass, meat and eating quality. *Meat Science*, 73(1), 157–165.
- Thompson, J. M. (2002). Managing meat tenderness. *Meat Science*, 62(3), 295–308.
- Walling, G. A., Visscher, P. M., Wilson, A. D., McTeir, B. L., Simm, G., & Bishop, S. C. (2004). Mapping of quantitative trait loci for growth and carcass traits in commercial sheep populations. *Journal of Animal Science*, 82(8), 2234–2245.
- Wheeler, T. L., Shackelford, S. D., & Koohmaraie, M. (2010). Warner–Bratzler Shear Force Protocol. <<http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/Warner-BratzlerShearForceProtocol.pdf>>.