Incorporating meat quality into commercial sheep breeding programmes

A project undertaken by
Innovis Ltd, IBERS and Dalehead Foods
with support from Hybu Cig Cymru

FINAL REPORT

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Summary

- A relationship between low muscle density measured using CT, increased intramuscular fat and improved eating quality has been previously established. The objective of this trial was to investigate the consequences of using CT muscle density as a selection criterion in a terminal sire line of sheep.
- 122 Abermax ram lambs were CT scanned and five low muscle density lambs and five high muscle density lambs were selected for use in a progeny test. The difference in average muscle density of the groups was approximately 4 standard deviations.
- The selected ram lambs were used to inseminate 230 North Country Mules at Syles Farm and in March 2012 395 lambs were born. Lambs were raised on grass following the usual management regime and selected for slaughter using the usual criteria for the farm (targeting 18-21kg carcass and fat class of 2-3H).
- 200 lambs (19-21 per sire) were followed through to processing and primal weights recorded. Loin samples were retained and used for sensory analysis, shear force testing and fatty acid and mineral analysis.
- The progeny of the low average muscle density sire were slightly heavier at 8 and 16 weeks of age (3-4%), and took an average of one day less to reach selection for slaughter. However these differences were not quite statistically significant in relation to the variation between individual sires.
- When compared at equal carcass weight the lambs of low muscle density sires appeared to have slightly higher ultrasonic backfat and lower muscle depth over the loin immeditately before slaughter, but these differences were not statistically significant. Both hot and cold carcass weight of the progeny of the low muscle density sires were lower (by ~ 2%) than the progeny of high muscle density sires and they had a lower killing out percentage. These differences between the low and high groups were statistically significant in relation to variation between individual sires.
- There were no significant difference in average carcass fat grade but the progeny of high muscle density lambs had significantly higher conformation grades (20% E+U compared to 13%).
- Analysis of primal weights showed that the progeny of high muscle density group had significantly higher saleable meat (3%) although as a proportion of cold carcass weight this was not significantly different to the low muscle density group. The difference in saleable meat was due to heavier loins (3%), shoulders (3%) and legs (3%). There were significant differences between individual sires in the proportion of the carcass that was loin, shoulder and breast but not between the high and low muscle density groups.
- The mean shear force measurement of the loin of the low muscle density progeny was lower than that of the high muscle density progeny (by 9%); this was very close to statistical significance in relation to variation between individual sires.
- There were no significant differences in fall of pH between the two groups of lambs, but the ultimate pH was slightly lower in the low muscle density lambs. The loin of the low muscle density lambs had significantly higher mean redness and colour saturation measurements.
- The progeny of low muscle density sires were consistently rated more favourably by the taste panel in all aspects of eating quality, although the differences were not statistically significant in relation to the variation between individual sires.
- The progeny of low muscle density sires had 10% more intramuscular fat compared to the progeny of high muscle density sires, but this difference was not statistically significant.
- It is recommended that CT average muscle density is routinely reported for all terminal sires lambs CT scanned, and that this information used to establish a robust data set for more accurate evaluation of genetic relationships between CT muscle density and muscling.
- The findings of the project suggest that a measure of CT muscle density would be useful in a genetic improvement programme to improve eating quality in lamb but it is essential that this information is used alongside measures of growth and muscling to avoid any reduction in carcass value.

Aims

This project undertook a large, industry scale “high / low” trial to try to establish some of the essential elements required to incorporate meat eating quality and nutritional value into commercial sheep breeding objectives. The project investigated the relationship between muscle density (as measured by computerised tomography, CT) in Innovis terminal sire lambs and intramuscular fat levels, and hence with eating quality in commercial crossbred lambs.

Background

Domestic consumption of lamb has been falling over the last two decades, and lamb has a significantly lower frequency of consumption than other sources of protein in the UK. For many (about 40%) consumers, lamb is an occasional meat of choice consumed less than once a month, and its pricing means that it is a premium product (around £8 per kg). Eating quality is of paramount importance for a premium product that is eaten only occasionally, and in order to sustain or increase levels of consumption it is important that consumers associate lamb with a consistently superb eating experience. In order to maintain a thriving sheep industry that maintains its vital contribution to the rural and national economy the opportunity to improve lamb eating quality, and thus increase the frequency of consumption among the UK and EU population needs to be seized.

Many factors from the birth of the lamb to its packaging and cooking as a cut of meat may influence eating quality. However, in trials designed to test the effect of measures applied on commercial farms and abattoirs, it has been shown that a substantial proportion of the differences in texture, juiciness and flavour are attributable to variation between individual animals that is probably genetic in origin. Genetic improvement could provide a cost effective and permanent means of improving the eating quality of lamb.

Public health campaigns have made the consumer increasingly aware of the nutritional quality of their food and there is potential for also increasing the consumption of lamb through promoting and improving its nutritional quality, in terms of fatty acid profile and the provision of essential nutrients such as zinc and iron. Previous studies have shown that there is genetic variation between individuals in the fatty acid composition of meat and the concentration of the essential nutrients, zinc and iron. The potential of improving nutritional quality of lamb through genetic improvement is therefore, also worthy of further investigation.

Previous studies have indicated that muscle density measured by computerised tomography (CT) in the live lamb is both highly heritable and has a strong negative correlation with eating quality – so lambs with LOW muscle density appear to have BETTER eating quality. The muscle density measurement, which is expressed in Houndsfield units (HU), is based on the average values of the pixels segmented as muscle in the CT images. Muscle density measurements have a strong negative correlation with intramuscular fat levels (Karamichou *et al,* 2006; Navajas *et al*, 2008; Lambe *et al*, 2010) and have been shown to be correlated with flavour, juiciness and overall palatability of lamb (Karamichou *et al*, 2006). Whereas increasing intramuscular fat to improve eating quality may be desirable, this would be expected to lead to an increase in overall carcass fatness, which would be undesirable. Increasing carcass fatness in total increases trimming and disposal costs for the processor and thus reduces the value of the lamb carcass.

Although the relationship between CT measurements of muscle density and eating quality have been established in various populations of sheep (Karamichou *et al,* 2006; Navajas *et al*, 2008; Lambe *et al*, 2010), and other species, the effect of actually using average CT muscle density as a selection criterion in a sheep breeding programme has never been investigated. This project undertook a large, industry scale “high / low” trial to try to establish if selection for low average CT muscle density in breeding rams would indeed result in the favourable eating quality of commercial crossbred lambs that has been predicted on the basis of previous research studies. This also allows us to evaluate correlated changes in growth, carcass and eating quality that might be result from the incorporation of CT average muscle density as a selection criterion.

Materials and Methods

Measurement of CT muscle density in Abermax ram lambs and selection of sires

198 Innovis Abermax ram lambs, the progeny of 7 high index sires, were born in March 2011. Weight was recorded at birth and at various points thereafter. Fat depth and muscle depth were measured by ultrasonic scanning at the deepest point of the *m*. *longissimus thoracis et lumborum* at an average age of 140 days. 122 were CT scanned at an average age of 22 weeks. The mean live weight at CT scanning was 46 ± 0.5 kg. Average muscle density was measured in a cross-sectional scan taken at the 5th lumbar vertebra.

From the 122 lambs CT scanned 5 high average muscle density and 5 low average muscle density individuals were identified as sires for the trial and trained for semen collection.

Progeny test of selected high and low muscle density ram lambs

The 10 selected ram lambs were used in an artificial insemination mating programme to inseminate 230 North Country mule ewes at Syles Farm in October 2011. Ewes were randomly assigned to rams on the basis of age and all ewes were managed as one flock following insemination. Progeny lambs (n=395) were born over a ten day period in March 2012. Pedigree and birth status, dam information, adoption and death were recorded at lambing. The MyoMAX® status of lambs was determined if their sire carried a single copy of the allele. Lambs were reared on grass and weaning occurred at 22 weeks (mean age 154d ± 0.08). Live weights were recorded at: birth; approximately 8 weeks (mean age 58 d ± 0.09 se); approximately 16 weeks (mean age 103 d ± 0.08 se); and pre-slaughter (mean age 147 d ± 1.1 se). Lambs were selected for slaughter on commercial criteria (target carcass weight: 18-21kg and fat class of 2-3H) on four occasions by the farm's existing lamb buyer.

Slaughter and carcass measurements

Animals were weighed and ultrasonically scanned prior to despatch to the abattoir (slaughter live weight). Fat depth and muscle depth were measured ultrasonically at the deepest point of the *m*. *longissimus thoracis et lumborum*. Lambs were slaughtered at H R Jasper & Son Ltd in four batches on the dates 11 July, 1 August, 22 August and 5 September 2012. Lambs were individually identified and carcasses were classified by the same grading staff for carcass weight, EUROP fat class and conformation scores.

Three hours after slaughter pH and temperature were measured at the loin (*paosa minor*) and the *semimembranosus* (topside). Within 24 hours the carcasses were transported to the cutting plant of Dalehead Foods in a chilled transporter (3°C). At 45 hours following slaughter cold carcass weight was recorded and ultimate pH was recorded in the loin (*paosa minor*) at 48 hours post slaughter. 200 carcasses (20 per sire) were then split into primal joints (shoulders, breasts, loins, legs) and the weights of these recorded. Parts of the carcass regarded as waste (neck and ribcage joined, pelvic bone, paddy wack, fat trim and bone trim) were also weighed in slaughter batches 2-4. The weights of the primal joints were used to calculate total saleable meat, fat waste and bone trim as a proportion of cold carcass weight.

The loins were split into two halves, and vacuum packed, for use in further analytical tests. The loin cut destined for use in sensory analysis and shear force testing were left with bone attached and aged for 7 days, before the bone was removed, and the loins were re-packaged and frozen. The portion of loin for laboratory analysis was not aged before freezing.

Shear Force testing

Shear Force was measured using the MIRINZ tenderometer (Tenderscot) on a 100 g sample from the rear right loin (post thawing) that had been cooked until it reached an internal temperature of 75˚C in a water bath for 90 minutes and chilled overnight. The tenderometer determined the force (in Newtons) required to shear through a 10mm x 10mm cross sectional sample at right angles to the fibre axis.

Colour

The 9 loin steak pieces (2cm depth) were left to bloom for an hour underneath oxygen permeable clingfilm. The colour coordinates (L* represents luminosity, a*redness and b* yellowness) of the loin were determined (average of 3 measurements) using a Minolta Chroma Meter CR-200 (Minolta Camera Co, Osaka, Japan). Colour saturation (chroma) of each sample was calculated as $\sqrt{(a^{*2}+b^{*2})}$.

Sensory analysis

Individual loin samples, thawed at room temperature, were cut into approximately 9 steak pieces (2cm depth), allowed to bloom for colour evaluation and then cooked under a grill until the internal temperature reached 72°C. The samples were wrapped in foil and presented in a hotbox to ten trained assessors (BS 7667) who were asked to rate the meat on an eight point category scale for six characteristics (described in Appendix 1).

Fatty Acid Analysis

Fatty acid analysis was carried out using gas chromatography, following freeze drying and bimethylation of trimmed samples of loin muscle, using the method described in Lee *et al* (2012). Total fatty acids were taken as the sum of all the fatty acids quantified. The concentrations of individual fatty acids were then grouped into sub-classes of saturated (SFA: C12:0, C14:0, C16:0, C18:0) monounsaturated (MUFA: C18:1 *cis*-9, C18:1 *cis*-11, C18:1*trans*-11, C20:1), polyunsaturated (PUFA: C18:3*n*-3, C20:3*n*-3, C20:5*n*-3, C22:5*n*-3, C22:6*n*-3, C18:2*n*-6, C18:3*n*-6, C20:3*n*-6, C20:4*n*-6, C22:4*n*-6) fatty acids *and n*-3 (C18:3*n*-3, C20:3*n*-3, C20:5*n*-3, C22:5*n*-3, C22:6*n*-3) and *n*-6 (C18:2*n*-6, C18:3*n*-6, C20:3*n*-6, C20:4*n*-6, C22:4*n*-6) associated fatty acids.

Mineral Analysis

Duplicate aliquots of 0.5g (±0.005) of freeze dried meat were weighed into 20ml digestion tubes. 5ml concentrated nitric acid was added using a pipette to each tube and allowed to stand for 12-18 hours at room temperature. Tubes were placed into a digestion block for 4 hours at 110 ± 5°C. The samples were allowed to cool for at least 15 minutes until a pale yellow colour was observed.

Samples were quantitatively transferred to 25ml volumetric flasks with deionised water and were made up to volume, samples were mixed well. Contents were then filtered through Whatman 542 filter papers into numbered sterelin tubes. Zinc and Iron content were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Statistical analysis

The data recorded on the Abermax ram lambs was adjusted for the effects of rearing type and dam age, where these were significant, prior to calculation of means and correlations.

Progeny data was analysed using a REML model with sire nested within high and low muscle density groups and sex, dam age (2yr *v*.older), rear type (single/ twin/ artificially reared), MyoMAX® status (carrier, non-carrier, unknown) and slaughter batch (1 to 4) were fitted as fixed effects where appropriate and significant. Pre-slaughter live weights and growth traits were adjusted to a constant age at measurement (with the exception of days to slaughter) and post slaughter traits were adjusted to a constant slaughter weight. The carcass fat class scores were converted into estimated subcutaneous fat proportion according to Kemspter *et al* (1986) : 1=40g/kg, 2=80g/kg, 3L= 110g/kg, 3H = 130g/kg, 4L= 150g/kg 4H=170g/kg, 5=200g/kg. Conformation scores were transformed into a numerical scale E =5, U=4, R=3, O=2, P=1. Ultrasonic fat depth, fat and conformation class, colour measurements and fatty acid concentrations were transformed by log 10 to improve normality of data.

Results

CT measurements in Abermax ram lamb population

A summary of the CT measurements of the ram lambs is shown in Table 1.

Table 1. Summary of CT measurements in 122 Abermax ram lambs.

	All ram lambs			**Selected ram lambs (Muscle density group)**				
				Low		**High**		
Trait	**Mean**	**sd**	**CV**	**Mean**	**se**	**Mean**	**se**	**Sig.**
Birth weight (kg)	5.3	1.1	20%	5.6	0.49	5.7	0.52	NS
Ultrasonic Fat Depth (mm)	1.75	0.6	34%	1.82	0.268	1.69	0.285	NS
Ultrasonic Muscle Depth (mm)	31.4	2.8	9%	28.6	1.26	31.9	1.34	NS
Average daily gain to CT scan (g/day)	281	30.2	11%	270	15.1	290	15.6	NS
Live weight at CT scan (kg)	48	4.8	10%	47	2.4	50	2.5	NS
CT Fat weight (kg)	4.3	1.0	22%	4.1	0.43	4.7	0.46	NS
CT Muscle weight (kg)	14.4	1.6	11%	13.9	0.79	15.1	0.82	NS
CT Gigot shape	6.1	0.7	11%	5.8	0.30	5.9	0.31	NS
CT Predicted Killing Out %	0.47	0.0	3%	0.46	0.008	0.48	0.008	NS
CT Average muscle density (HU)	41.6	1.5	4%	38.5	0.73	44.6	0.72	P<0.001
CT muscle density sd (HU)	17.7	0.7	4%	17.3	0.32	18.0	0.32	NS

HU: Houndsfield Units

The level of variation was low for CT average muscle density (CV=4%) in this population of ram lambs. Nevertheless it was possible to select a group of 5 high average muscle density and five low average muscle density lambs that differed in average muscle density by 4 standard deviations. The low muscle density group had a slightly lower muscle depth (10%) and CT muscle weight (8%) than the high muscle density group, but these differences were not statistically significant.

Figure 1. Boxplots of CT traits recorded on selected high and low muscle density lambs relative to unselected (other) lambs.

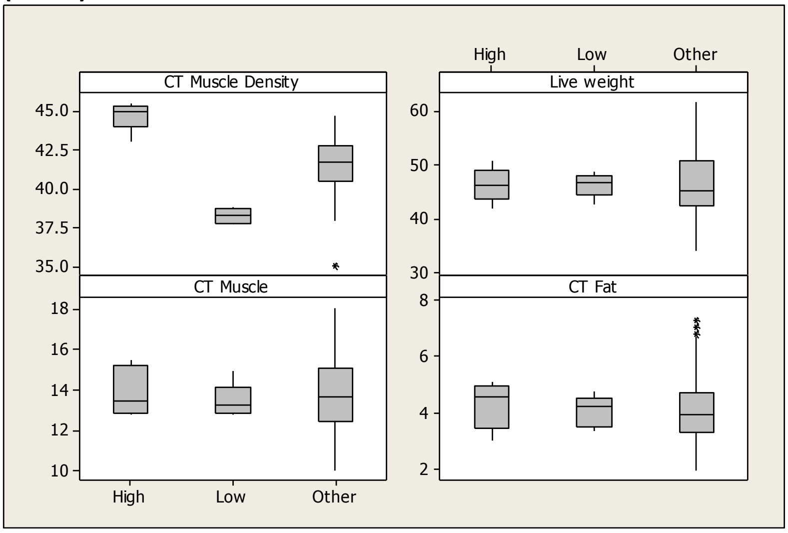


Figure 1 illustrates the distribution of CT muscle density of the selected lambs relative to unselected (other) lambs, and also their live weight and CT muscle and fat weights. This shows that although a considerable difference between the two groups was achieved for muscle density the lambs selected as sires were very similar in all other important characteristics.

The estimated phenotypic correlations among the traits recorded in the 122 ram lambs are shown in Table 2.

Table 2. Phenotypic correlations among traits recorded in 122 Abermax ram lambs.

						CT measurements				
	Birth wt	US Fat	US Muscle	ADG	Live wt	Fat	Muscle	Gigot	KO%	MD
US Fat	0.01									
US Musc.	**0.29**	**0.22**								
ADG	**0.20**	**0.36**	**0.50**							
Live wt	**0.36**	**0.36**	**0.54**	**0.97**						
CT Fat	**0.25**	**0.60**	**0.46**	**0.80**	**0.80**					
CT Musc.	**0.29**	**0.21**	**0.53**	**0.35**	**0.39**	**0.50**				
CT Gigot	0.14	0.18	**0.51**	**0.40**	**0.39**	**0.28**	**0.33**			
CT KO%	**0.42**	**0.21**	**0.64**	**0.87**	**0.92**	**0.65**	**0.61**	**0.46**		
CT MD	0.11	-0.07	**0.18**	-0.08	-0.05	-0.17	**0.18**	0.14	0.13	
CT MD SD	-0.09	**0.18**	0.04	**0.18**	0.15	**0.32**	0.11	-0.08	0.04	-0.19

Correlations given in bold are significantly different to zero.

CT average muscle density was positively correlated with both ultrasonic muscle depth and CT muscle weight, showing that animals with more muscling also tended to have a higher muscle density measurement. The negative correlation of CT average muscle density and CT fat weight was approaching significance (P=0.06), suggesting that fatter animals tend to have lower muscle density measurements. The standard deviation of muscle density (CT MD SD), which relates to the distribution of fat within the muscle, was positively correlated with both ultrasonic fat depth and CT fat weight.

Abermax ram lamb population - Key Findings

There was little phenotypic variation in muscle density measurements (CV=4%).

The ram lambs selected as sires differed in muscle density measurements, but were otherwise very similar.

In the group of ram lambs CT scanned there was a tendency for well muscled animals to have higher muscle density measurements.

Growth and carcass quality of the crossbred lambs

A summary of the growth of the lambs is shown in Table 3. The progeny of the low average muscle density sire were slightly, but not significantly, heavier at 8 and 16 weeks of age (3-4%), and took an average of one day less to reach selection for slaughter. There was significant variation between the progeny of individual sires within muscle density group for all the live weights but not the growth rates.

Table 3. Summary of growth traits in crossbred progeny lambs (adjusted to a uniform age).

		Sire muscle density group			
		Low	High		
Trait	**n**	**Mean**	**Mean**	**SED**	**Sig.**
Birth weight (kg)	394	6.0	6.0	0.17	NS
8 week weight (kg)	368	25.2	24.5	0.46	NS
16 week weight (kg)	342	34.9	33.9	0.58	NS
8 week ADG (g/day)	346	320	319	6.3	NS
8-16 ADG (g/day)	342	262	252	6.9	NS
16 week ADG (g/day)	342	284	278	4.9	NS
Days to slaughter	252	147	146	0.75	NS

The carcass quality measurements recorded on the lambs are summarised in Table 4.

Table 4. Summary of carcass quality measurements in crossbred progeny lambs (adjusted to a uniform slaughter weight: 42.8 kg).

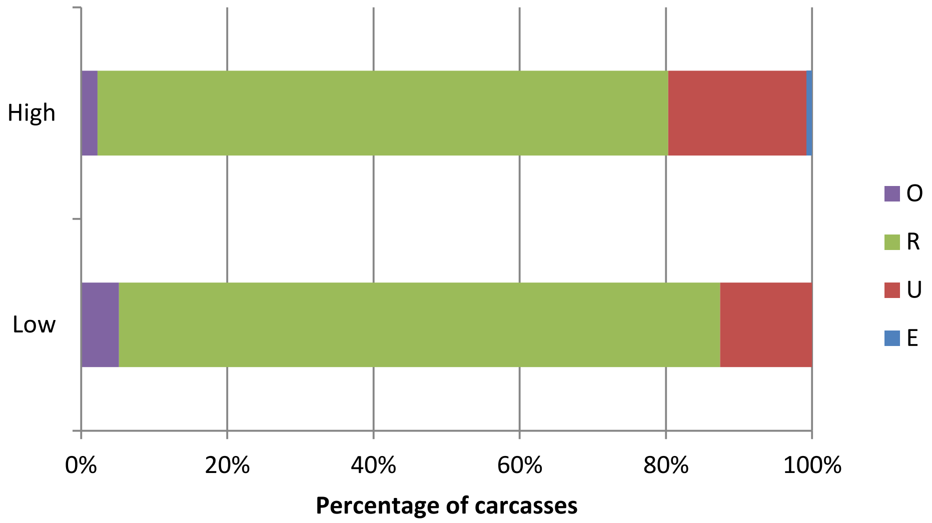
		Sire muscle density group			
		Low	High		
Trait	**n**	**Mean**	**Mean**	**SED**	**Sig.**
Slaughter ADG (g/day)	252	255	256	1.6	NS
Log, US fat depth (mm)	264	0.42 (†2.6)	0.39(†2.4)	0.027	NS
US muscle depth (mm)	252	25.7	26.4	0.42	NS
Hot carcass weight (kg)	252	19.8	20.2	0.15	P<0.05
48hr cold carcass weight (kg)	246	19.2	19.7	0.17	P<0.05
Killing out %	252	45.0	46.0	0.34	P<0.05
Log conformation	252	0.48 (R)	0.50 (R+)	0.009	P<0.05
Log fat class	252	0.97(3L-)	0.96(3L-)	0.013	NS

† Geometric mean or equivalent grade based on geometric mean

The progeny of low muscle density sires had a slightly higher average ultrasonic fat depth at slaughter (5%), and lower muscle depth (4%) but these differences were not statistically significant. They produced significantly lighter (2%) carcasses and had a significantly lower killing out percentage. There were no significant differences in carcass fat grade but the better muscled progeny of the high muscle density lambs were better conformed and had a significantly higher average conformation grade. Of lambs sired by high muscle density sires 20% graded as E or U compared to 13% of lambs sired by low muscle density sires (see Figure 2).

In addition to differences between the progeny of high and low muscle density sires there was also significant variation between the progeny groups of individual sires for all the carcass quality measurements except carcass conformation grades. The result suggest that although the progeny of low muscle density sires appear to grow slightly better, they kill out less well and are slightly less muscled and less well conformed compared to the progeny of high muscle density sires at the same slaughter weight.

Figure 2. Summary of carcass conformation grades in groups of crossbred lambs sired by rams selected for high or low CT average muscle density.



The higher average carcass weight and better carcass conformation of the lambs sired by high muscle density rams was reflected in the primal weights (summarised in Table 5), with these lambs having significantly higher weights for the loin and the leg and significantly higher total saleable meat. The shoulders of the progeny of high muscle density lambs were also heavier although this difference did not quite reach statistical significance (P=0.07). Nevertheless, there was no difference between the two groups of lambs in carcass proportions, either of total saleable meat or individual primals. There were significant differences between individual sires for most of the primal weights and proportions except fat trim and the proportion of the carcass in the leg.

Table 5. Summary of primal weights and proportions in crossbred progeny lambs (adjusted to a uniform slaughter weight: 42.8 kg).

Trait		Sire muscle density group			
Primal Weights	**n**	**Low**	**High**		
		Mean	**Mean**	**SED**	**Sig.**
Breast (kg)	199	1.76	1.76	0.040	NS
Shoulder (kg)	199	4.16	4.28	0.059	P=0.074
Loin (kg)	199	3.17	3.27	0.039	P<0.05
Leg (kg)	199	5.52	5.71	0.057	P<0.05
Total Saleable Meat (kg)	198	14.58	15.00	0.123	P<0.05
Fat Trim (kg)	153	0.66	0.65	0.017	NS
Bone Waste (kg)	154	3.81	3.83	0.052	NS
Primal proportions (of total)					
Breast	194	0.09	0.09	0.003	NS
Shoulder	193	0.22	0.22	0.002	NS
Loin	196	0.17	0.17	0.004	NS
Leg	193	0.29	0.29	0.001	NS
Total Saleable Meat (kg)	192	0.76	0.76	0.001	NS
Fat Trim (kg)	151	0.03	0.03	0.003	NS
Bone Waste (kg)	149	0.20	0.20	0.002	NS

Growth and carcass quality of crossbred progeny - Key Findings

The progeny of low muscle density sires tended to grow slightly quicker – but this was not statistically significant.

The progeny of high muscle density sires had a significantly higher killing out percentage and thus produced slightly heavier and also better conformed carcasses.

The higher carcass weight of the progeny of the high muscle density sires was due to heavier legs, loins and shoulders.

There were no differences in the distribution of meat and waste within the carcasses between the groups of lambs sired by low and high muscle density rams.

Meat quality of the crossbred lambs

The loins of the progeny of low average muscle density sires tended to have lower shear force than those of the progeny of high muscle density sires, although this difference was not quite statistically significant (P=0.07). There were no significant differences between the groups in either the ultimate pH or the drop in pH. The loin chops from progeny of low muscle density sires had significantly higher colour saturation and redness. These results are summarised in Table 6.

Table 6. Summary of meat quality measurements in the loin of crossbred progeny lambs (adjusted to a uniform slaughter weight: 42.8 kg).

Trait	n	Sire muscle density group Low	High		
		Mean	Mean	SED	Sig.
Shear Force (N)	200	29.6	32.0	1.10	P=0.067
Colour					
Saturation (Log C)	184	1.24(†17.5)	1.23(†17.0)	0.005	P<0.05
Lightness (Log L*)	184	1.64(†43.5)	1.63(†43.2)	0.003	NS
Redness (Log a*)	184	1.21(†16.2)	1.20(†15.7)	0.005	P<0.05
Ultimate pH (LV4)	205	5.71	5.69	0.011	NS
pH Difference	179	0.00	0.02	0.018	NS

† Geometric mean

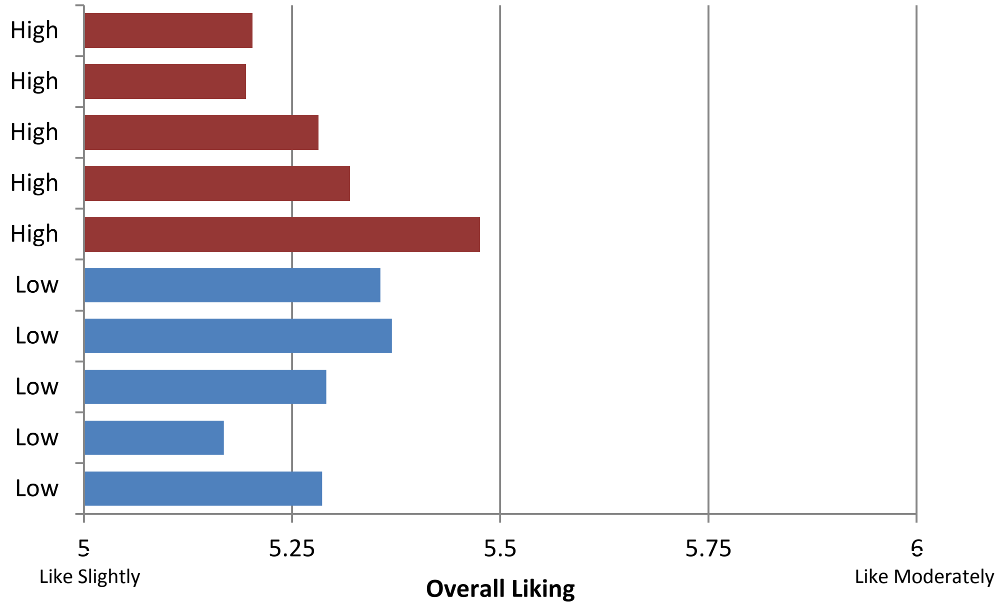
Eating quality of the crossbred lambs

The progeny of low muscle density sires consistently received more favourable ratings than the progeny of high muscle density sires for all aspects of eating quality (summarised in Table 7). However, these differences were not statistically significant in relation to the variation between individual sires which was significant for texture, juiciness and overall liking. In terms of individual sires the progeny of 4 of the 5 low density sires had an average rating of 5.25 or above for overall liking (see Figure 3). It should be noted that the loin samples in this study received high eating quality ratings compared to previous studies: the mean ratings for female lambs in the study of Nute *et al* (2007), which looked at gender effects on eating quality, were 4.64, 3.20, 5.56, 5.07 and 4.60 for flavour liking, abnormal flavour intensity, texture, juiciness and overall liking respectively.

Table 7. Summary of eating quality measurements in the loin of crossbred progeny lambs (adjusted to a uniform slaughter weight: 42.8 kg).

Trait	n	Sire muscle density group Low	High		
		Mean	Mean	SED	Sig.
Flavour liking (8 = Like extremely)	184	5.61	5.59	0.054	NS
Abnormal flavour (8= Extremely Strong)	184	2.19	2.21	0.028	NS
Texture (8 = Extremely Tender)	184	5.68	5.56	0.108	NS
Juiciness (8= Extremely Juicy)	184	5.11	5.01	0.080	NS
Overall Liking (8= Like Extremely)	184	5.32	5.27	0.091	NS

Figure 3. Mean Overall liking score of progeny groups of individual sires.



Fatty acid analysis of loin samples of the crossbred lambs

Total intramuscular fat was slightly higher (by 10%) in the loin of lambs sired by low muscle density sires compared to the progeny of high muscle density sires but this difference was not statistically significant (P=0.16)(see Table 8). Both saturated (SFA) and monounsaturated (MUFA) fatty acids were slightly more concentrated in the progeny of low muscle density sires but there were virtually no differences in polyunsaturated fatty acids (PUFA).

Table 8. Summary of fatty acid and mineral analysis of the loin of crossbred progeny lambs (adjusted to a uniform slaughter weight: 42.8 kg).

		Sire muscle density group			
	n	Low	High		
Fatty Acids		**Mean**	**Mean**	**SED**	**Sig.**
Log Total IM Fat (mg/g)	197	3.41(†2546)	3.36(†2312)	0.028	P=0.16
Log SFA	197	3.02(†1037)	2.97(†942)	0.031	NS
Log MUFA	197	2.96(†920)	2.91(†817)	0.035	NS
Log PUFA	197	2.42(†265)	2.42(†261)	0.011	NS
Log n-6	200	2.05(†113)	2.06(†114)	0.010	NS
Log n-3	200	2.03(†106)	2.03(†106)	0.011	NS

† Geometric mean

Meat and eating quality of crossbred progeny - Key Findings

The progeny of low muscle density sires tended to have more tender loins.

The loins of the low muscle density group were also redder and had significantly more colour saturation.

The progeny of low muscle density sires were consistently rated more favourably by the taste panel in all aspects of eating quality, although the differences were not statistically significant.

The progeny of low muscle density sires had 10% more intramuscular fat compared to the progeny of high muscle density sires, but this difference was not statistically significant.

Implications of the project findings

Selecting terminal sire ram lambs on the basis of muscle density

Although the variation of muscle density measurements among the Abermax ram lambs was relatively low, compared to variation in other traits, for example fat depth or growth rate, high and low muscle density ram lambs were successfully selected. The selection differential achieved was roughly equivalent to that which would be achieved if the best 1% of animals were selected on the basis of muscle density measurement. Low phenotypic variation in a trait is normally associated with low rates of genetic gain, however, in the case of muscle density measurements previous studies have suggested that heritability of the trait is relatively high (0.3, Lambe *et al*, 2010; 0.45, Karamichou *et al*, 2006), which means that the levels of genetic variation are likely to be sufficient to allow a good selection response.

In the population of ram lambs that were CT scanned in this project there was a positive phenotypic correlation between muscle density measurement and both ultrasonic and CT measurements of muscling (see below).

Impact of muscle density on lamb growth and carcass measurements

	LOW	HIGH
Growth	+	
Muscling		+
Killing out %		++
Carcass conformation		+
Carcass fat	**Minimal difference**	
Bone waste	**Minimal difference**	

Previous studies (Lambe *et al* , 2010; Karamichou *et al*, 2006) have found significant negative correlations with measures of fatness but not muscling. However, these studies were carried out in the Scottish Blackface in which the average level of muscling is considerably lower than in the Abermax ram lambs used in this study. The results of this project suggest that if it is desirable to decrease muscle density it would be necessary to include it in an index alongside appropriate measures of muscling in order to ensure that animals that had both good muscling and low muscle density scores were identified for the breeding programme. In order to weight traits correctly in an index more accurate estimates of the heritability of muscle density and its genetic correlation with other CT traits in terminal sires breeds is required. With approximately 400 terminal sire ram lambs CT scanned each year in the UK sufficient data for accurate estimation of the genetic parameters should be available if CT muscle density were to be routinely recorded.

In this study there was a positive correlation between the standard deviation of the muscle density measurement (CT MD SD), which relates to the distribution of fat within the muscle, and both ultrasonic fat depth and CT fat weight. It is possible that this measure, in addition to average CT muscle density, may prove useful and the relationship of this trait with levels of intramuscular fat and eating quality is worthy of further investigation.

Would selecting on muscle density improve eating quality?

The progeny of low muscle density sires had higher levels of intramuscular fat and consistently superior meat and eating quality in ***all*** the criteria assessed (see below), however, this advantage was rarely statistically significant. The lack of statistical significance was largely due to the comparatively high levels of variation between individual sires within the muscle density groups, and it is likely that if more sires had been used many of these differences would have achieved statistical significance.

Impact of muscle density on meat quality measurements

	LOW	**HIGH**
Colour	**+**	
pH	**Minimal difference**	
Tenderness	**+**	
Eating	**+**	
Intramuscular fat	**++**	
Fatty acids	**Minimal difference**	

The consistency of the results across the whole range of measures together with the agreement with expectations based on previously published work (Karamichou *et al*, 2006; Lambe *et al*, 2008) suggest that the use of muscle density measurements, in combination with other measures of carcass quality, can be used in a breeding programme to improve aspects of eating quality.

As with selection for any trait, and given the scale of differences in eating quality seen in this study, the rate of genetic improvement in eating quality is likely to yield only small annual benefits, but in the longer term the cumulative effects are likely to be significant and contribute positively to consumer satisfaction. Alternative methods currently available for improving eating quality through selection would involve lengthy and expensive progeny tests, and whilst this may result in a higher accuracy of selection compared to the use of a measure of CT muscle density, the increases in generation interval and cost of this approach would make it less cost effective. In the future the use of genomic breeding values offers a promising alternative approach but will require the establishment of extensive and detailed data sets on eating quality traits on several thousand genotyped animals before it can be implemented. Therefore, in the short term, the use of CT muscle density measurements offers the most cost effective route to genetic improvement in eating quality.

Would selecting on CT muscle density have any "side effects"?

In this study the progeny of rams selected for low muscle density had significantly lower killing out percentage and so produced slightly lighter carcasses at the same slaughter weight as the progeny of rams selected for high muscle density. They also tended to have slightly lower conformation grades. Both these effects are undesirable for both farmer and processor as it reduces the value of the carcass.

These results emphasise the need to incorporate CT muscle density measurements into a selection index alongside measures of growth and muscling so that genetic improvement in eating quality does not result in unfavourable correlated changes in carcass quality and value. The use of such a selection index will allow the identification of animals that are likely to have both improved eating quality and improved carcass value.

The results also suggest that intense selection for highly muscled animals that kill out well and achieve good conformation grades could result in lower eating quality in the long term. Clearly a greater understanding of the genetic correlations between eating quality and muscling are required to guard against this possibility.

In this project there was no evidence of significant differences in the level or quality of fat in the carcasses of the lambs sired by high and low muscle density ram lambs, which was expected on the basis of previous studies. The progeny of low muscle density sires did have slightly, but not significantly, higher levels of intramuscular fat (+10%), but only marginally higher levels of fat trim in the carcass and fat score on the basis of carcass classification (+1%).

Recommendations

The use of CT average muscle density measurements in terminal sire breeding programmes offers a current and cost effective means of maintaining and improving eating quality.

Measures of CT average muscle density should be used alongside measures of growth and muscling to improve overall carcass value and eating quality. Use of muscle density measurements alone could result in decreased carcass value for both farmer and processor.

Routine reporting of CT average muscle density for all lambs that are CT scanned would ensure robust data sets were established that would allow the estimation of more accurate genetic parameters to be used in the construction of an appropriate selection index.

A greater understanding of the genetic relationships of muscling and eating quality in lamb carcasses would benefit farmers, processors, retailers and consumers.

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References

Karamichou E, Richardson R I, Nute G R, McLean K A and Bishop S C (2006) Genetic analyses of carcass composition, as assessed by X-ray computer tomography, and meat quality traits in Scottish Blackface sheep. Animal Science **82**: 151–162

Lambe N R, Navajas E A, Schofield C P, Fisher A V, Simm G, Roehe R and Bünger L (2008) The use of various live animal measurements to predict carcass and meat quality in two divergent lamb breeds Meat Science **80**:1138–1149

Lambe N R, Conington J, Navajas E A, McLean K A, Roehe R and Bunger L (2010) Genetic relationships between muscle density, measured by X-ray computed tomography (CT), and lamb growth and carcass traits. Advances in Animal Biosciences **1**: pp 134-134

Lee M R F , Tweed J K S , Kim E J and Scollan N D (2012) Beef, chicken and lamb fatty acid analysis — a simplified direct bimethylation procedure using freeze-dried material. Meat Science **92**: 863–866

Nute G R, Baker A and Hughes S I (2007) The effect of sex category on the eating quality of lamb loin chops.

Appendix 1 : 8 Point Category Rating Scales used in Sensory Evaluation

Attributes category scores 1-8
Assessors are asked to rate the samples on eight point category scales for texture, juiciness, flavour intensity (higher values denote more favourable responses), abnormal flavour intensity (lower values denote more favourable responses). Two additional hedonic questions relating to flavour liking and overall liking are also used.

8 Point Category Rating Scales used in the assessment of lamb.

Values are awarded after assessment.

Rating	**Texture**	**Juiciness**	**Flavour intensity**
8	Extremely Tender	Extremely Juicy	Extremely Strong
7	Very Tender	Very Juicy	Very Strong
6	Moderately Tender	Moderately Juicy	Moderately Strong
5	Slightly Tender	Slightly Juicy	Slightly Strong
4	Slightly Tough	Slightly Dry	Slightly Weak
3	Moderately Tough	Moderately Dry	Moderately Weak
2	Very Tough	Very dry	Very Weak
1	Extremely Tough	Extremely Dry	Extremely Weak

		Hedonic	
	Abnormal flavour intensity	**Flavour liking**	**Overall liking**
8	Extremely Strong	Like Extremely	Like Extremely
7	Very Strong	Like Very Much	Like Very Much
6	Moderately Strong	Like Moderately	Like Moderately
5	Slightly Strong	Like Slightly	Like Slightly
4	Slightly Weak	Dislike Slightly	Dislike Slightly
3	Moderately Weak	Dislike Moderately	Dislike Moderately
2	Very Weak	Dislike Very Much	Dislike Very Much
1	Extremely Weak	Dislike Extremely	Dislike Extremely