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Correlations among beef carcass composition and meat quality traits from a genetic marker trial

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ABSTRACT

A collaborative beef cattle project between AgResearch and Adelaide University is described, which had the aim of identifying genetic markers (DNA markers) for carcass composition and meat quality traits. Two extreme breeds were used, the Jersey and Limousin, and first-cross Jersey x Limousin bulls were mated to cows of both breeds to produce experimental animals in two herds, in New Zealand and Australia. The present paper provides information on relationships among some traits recorded in the New Zealand herd, with a total of 416 back-cross cattle of both sexes slaughtered as 2-year-olds at Ruakura in the springs of 1998 and 1999. The recorded data included hot carcass weight and the butcher-dissected weights of meat, fat and bone in the right side, expressed as percentages of side weight (MP, FP and BP respectively). The pH decline in the right striploin, removed from the carcass after dressing and maintained at a constant 15ºC, was monitored to derive the initial (pH1), ultimate (pHu), and the rate of fall of pH. Average shear force (SAVG) and the half-life of the ageing rate (SHLF) were measured in striploin steaks cooked immediately after *rigor* and then at intervals until ultimate tenderness. Percentage weight loss (PWL) during cooking was recorded. Also measured in the striploin were the concentrations of three metabolic enzymes, lactate dehydrogenase (LDH), isocitrate dehydrogenase (ICDH) and 3-hydroxyacyl-Coenzyme A dehydrogenase (HAD), and the proteolytic enzymes μ- and milli-calpain, and their inhibitor calpastatin (CAST). Glycogen concentration in the muscle at slaughter, expressed as the glycolytic potential (GLYP), was estimated from the sum of the concentrations at *rigor* of glucose, glucose-6-phosphate, lactate and residual glycogen. The range of pHu values was small, probably because all animals were regularly handled. Correlations, after adjustment for breed group, sire and slaughter group, included: MP with FP, -0.82; PWL with MP, 0.20; PWL with FP, -0.29; MP with enzymes LDH, ICDH and HAD, 0.22, -0.21, -0.03; FP with ICDH, 0.16; SAVG with SHLF, 0.48; SHLF with CAST, μ- and milli-calpain, 0.28, -0.14, 0.03; CAST with μ- and milli-calpain, 0.26, 0.38; GLYP with pH1 and pHu -0.01 and -0.17. Overall, HCW, MW and composition traits were not correlated with pH traits or SAVG, or μ- or milli-calpain concentrations; HCW and MW were positively correlated with LDH and GLYP.

Keywords: cattle; correlation; carcass composition; meat quality.

INTRODUCTION

A genetic marker (DNA marker) project was established in 1995 to search for quantitative trait loci affecting beef carcass composition and meat quality. The project is a collaboration between AgResearch and Adelaide University, producing animals in two experimental herds, one in each country (Morris *et al*., 2000a). Data analyses are still in progress. The present report summarises the relationships among carcass composition and meat quality traits in the back-crosses grown out and slaughtered in New Zealand.

MATERIALS AND METHODS

Design

A double back-cross genetic marker design was established in 1995, using bulls that were first crosses between two *Bos taurus* breeds known to be widely different in a number of performance traits. The two breeds were Jersey (J) and Limousin (L), and they differed, for example, in carcass composition, fat colour, marbling, milk yield, body size, age at puberty, as reported by Cundiff *et al.* (1986). Three pairs of half-brothers (two of the pairs being from J sire x L dams; the other pair being L x J) were generated as first crosses (X), and one of each pair was used for mating in each country over both J and L cows to breed back-cross cattle. In New Zealand, 261 experimental back-cross calves (162 XJ and 99 XL) were born in spring 1996, with another 155 born in spring 1997 (102 XJ and 53 XL). The XJ calves were born on dairy farms and were bucket-reared; the XL calves were born in 1996 by embryo transplant as singles or twins to Hereford x Friesian recipients, and in 1997 following artificial insemination of X bulls over L cows. In both years the XL calves were reared on their dams. Offspring were slaughtered at ages ranging from 22 to 28 months. In Australia, about 400 experimental back-cross calves were born over the 3 years 1996-98. This paper reports on relationships among the carcass composition and meat quality data from cattle from the New Zealand herd, processed at the Ruakura Experimental Abattoir.

Slaughter and dissection data

Animals were pre-allocated to slaughter groups in the springs of 1998 and 1999 over 18 and 10 kill days, respectively (once a week with approx. 15 same-sex animals per slaughter group, 18 groups in 1998 and 10 in 1999). Pre-allocation was based on breed of calf, sire, and balanced as far as possible within breed for live weight before the first slaughter day. Each animal was stunned by captive bolt and then slaughtered, with no electrical stimulation applied. After splitting the carcass and weighing the two sides (to give hot carcass weight (HCW)), the right striploin was removed and the right side was then stored in a chiller for 24 hours before quartering at the 10/11th rib. A butcher's dissection of the right fore- and hind-quarters was then

carried out in order to record, for each joint, the weights of saleable meat plus meat trim (the combined total being referred to as "meat"), trimmed fat ("fat") leaving a fat cover of approx. 2 mm, and bone.

Muscle measurements

Initial pH was recorded on the unstimulated striploin within about 30 minutes of slaughter ('pH1'), and pH was then monitored at intervals for about 24 hours until *rigor mortis*, with the temperature of the striploin held at 15ºC in a controlled-temperature cabinet. Ultimate pH ('pHu') was the lowest pH attained in the first 24 h, defining the full development of *rigor mortis*. Five steak portions from the striploin were then cut for cooking and shear-force measurement. The first steak was processed on reaching *rigor mortis*, and four subsequent steaks were cooked at intervals relative to the time of *rigor mortis* (but at approx. 1.3, 2.0, 2.3 and 4.0 days *post mortem*), after continued storage at 15ºC. For cooking, each steak was placed inside a plastic cooking bag, heated in a boiling water-bath to an internal temperature of 75ºC, then removed and cooled rapidly in ice to an internal temperature of 2ºC. Shear-force measurements were then recorded using a MIRINZ tenderometer (Fraserhurst & MacFarlane, 1983), taking the average from measurements of ten 1cm x 1cm cores, aligned with the fibre running longitudinally along the core. The weight of each steak, before and after cooking, was also recorded.

For metabolic enzyme activities, muscle samples weighing approx. 10g were taken from the striploin after dressing, chopped coarsely, frozen in liquid nitrogen and stored at -80°C until assayed. Activities of lactate dehydrogenase (LDH) and isocitrate dehydrogenase (ICDH) were measured as described by Bergmeyer *et al.* (1983), and 3-hydroxyacyl-CoA dehydrogenase (HAD) as described by Bass *et al*. (1969).

Micro- and milli-calpain, and calpastatin (CAST) were measured from fresh 5g striploin samples collected immediately after carcass dressing, as described by Wheeler and Koohmaraie (1991), with modifications (Sainz *et al.*, 1992).

Glycolytic potential (GLYP) of the striploin muscle was calculated from the combined concentrations of glycogen, glucose, glucose-6-phosphate and lactate in samples collected after *rigor*. The samples were kept frozen at -35°C until analysis, using the methods described by Daly *et al.* (1999). Results were expressed in C_3 lactate equivalents.

Statistical analyses

Weights of dissected components of the side were totalled for meat (MW), fat (FW) and bone (BW), and percentages were calculated (MP, FP and BP) relative to their total. The rate of fall of pH ('pHf') was linear at constant temperature, and calculated from a linear regression of measured pH values on time during the pre-*rigor* period. The half-life for the fall in shear force (SHLF) was taken by fitting an exponential decay function through the shear-force results from cook times 1 to 5 (Dransfield *et al.*, 1980-81), for the striploin of each animal separately. The average of the shear-force results at all five times was also calculated (SAVG). The percentage weight loss (PWL) of each steak during cooking was calculated from the steak weights, before and after cooking.

Results for 20 traits defined above were analysed using the JMP programme (SAS, 1995), fitting relevant fixed effects for breed group x birth-rank (n=3 classes, with one for XJ calves and two for XL calves to allow for singles and twins born), sire of calf and slaughter group, which effectively adjusted for sex and year as well. Residual standard deviations (RSD) were obtained for each trait, and the data for each animal (adjusted for fixed effects) were used to estimate correlations among traits. There were two years of data for most traits, but only the first year of data (63% of the total animals) were recorded for the three enzymes, the calpain system and GLYP.

RESULTS

Table 1 shows the overall means and residual standard deviations (RSD) of all 20 traits. HCW was greater in XL than XJ cattle by an average of 60 ± 2.2 kg or 30% ($P < 0.001$), and the composition of XL animals had an average of 5.1 ± 0.18, 2.5 ± 0.18 and 2.6 ± 0.11 percentage points more MP, less FP and less BP than that of XJ animals (all $P < 0.001$); (data not shown). Striploin muscles had low RSDs for pHu and pHf, whilst pH1 was relatively more variable. SAVG averaged 9.19 kgF, falling from 14.69 kgF at *rigor* (the first cook time) to 5.95 kgF at ultimate shear force. SAVG had a coefficient of variation (=RSD/mean) of 12%, whilst SHLF had a much larger coefficient of variation of 49%. The final seven traits in Table 1 had coefficients of variation ranging from 9-17% of their means. The XJ breed had a 5.3 ± 1.7% lower SAVG, an 0.12 ± 0.02 higher pH1, a 14 ± 3% higher GLYP and a 3.0 ± 0.2 percentage point lower PWL than the XL breed (all at least $P < 0.01$), whilst pHu did not differ between breeds.

TABLE 1: Overall means, abbreviations, and residual standard deviations (RSD) for carcass composition and meat quality traits, after adjusting for breed group, sire and slaughter group.

Trait		Units	Mean	RSD
Hot carcass weight	HCW	kg	229.1	21.8
Weight in right side				
Meat	MW	kg	74.82	7.37
Fat	FW	kg	9.55	2.18
Bone	BW	kg	23.96	1.86
Component in right side				
Meat	MP	%	69.36	1.81
Fat	FP	%	8.70	1.72
Bone	BP	%	21.96	1.05
Initial pH	pH1		6.86	0.15
Ultimate pH	pHu		5.44	0.02
Rate of fall in pH	pHf	/hr	-0.08	0.01
Average shear force	SAVG	kgF	9.19	1.13
Half-life of shear force change	SHLF	hr	12.13	5.96
Steak weight loss	PWL	%	23.11	4.31
Enzymes [a]	LDH	kilo u./g	196.9	17.7
	ICDH	units/g	530.8	82.0
	HAD	units/g	595.1	91.4
Calpain system [a]	μ-calp	i.u./g[b]	0.94	0.16
	m-calp	i.u./g[b]	1.27	0.16
	CAST	i.u./g[b]	3.22	0.44
Glycolytic potential	GLYP	lact.[c]	230.6	41.8

[a] LDH = lactate dehydrogenase; ICDH = isocitrate dehydrogenase; HAD = 3-hydroxyacyl-Co-A dehydrogenase; calpain system = μ-calpain, millicalpain and calpastatin.
[b] Per gram of wet tissue.
[c] Lactate equivalents.

TABLE 2: Correlations (x100) among carcass composition and meat quality traits; the absolute value of each correlation is significantly different from zero if > 0.10 (i.e. > 10 in the Table) when both years of data were available, or if > 0.17 when at least one trait had only one year of data recorded [the last seven traits]. Abbreviations are explained in Table 1.

	HCW	MW	FW	BW	MP	FP	BP	pH1	pHu	pHf	SAVG	SHLF	PWL	LDH	ICDH	HAD	μ-calp	m-calp	CAST
MW	95																		
FW	50	29																	
BW	84	76	40																
MP	10	33	-66	-9															
FP	16	-5	91	8	-82														
BP	-47	-52	-39	1	-30	-28													
pH1	-2	1	-7	7	-1	-8	14												
pHu	2	2	5	4	-5	4	1	12											
pHf	-1	-4	1	-3	-4	2	4	7	-15										
SAVG	-6	-7	-3	0	-5	-1	12	8	25	-4									
SHLF	-6	-9	7	4	-19	10	15	11	8	-3	48								
PWL	-5	-2	-26	1	20	-29	16	-4	1	-11	5	3							
LDH	28	30	9	4	22	0	-37	-12	-8	-5	-5	-12	-22						
ICDH	-8	-16	14	-1	-21	16	13	0	-1	-5	8	5	-3	4					
HAD	-8	-6	-3	-3	-3	-2	9	-3	1	-3	13	10	7	24	67				
μ-calp	0	5	2	1	2	2	-6	-1	-4	1	-27	-14	-1	9	-6	-6			
m-calp	-3	1	-1	-7	3	1	-5	1	6	-2	3	3	5	8	-3	-2	33		
CAST	-4	-11	17	0	-21	19	8	-6	1	-7	26	28	2	2	13	11	26	38	
GLYP	22	21	11	14	5	4	-15	-1	-17	1	-16	2	2	12	8	11	-5	3	3

Table 2 shows the correlations among all the traits from Table 1; significance levels are also defined. For three of the four weight (size) traits, HCW, MW and BW, correlations among them were high (0.76 to 0.95), but correlations were medium between these three traits and the fourth weight trait, FW (0.29 to 0.50). MP was positively correlated with MW (0.33), but negatively with FW and BW (-0.66 and -0.09). The sum of the three composition traits, MP, FP and BP, was 100%, so all correlations among them were expected to be negative; the correlation of MP with FP (-0.82) was particularly large. Size and composition were not correlated with pH or shear-force traits (the largest being -0.19 between MP and SHLF). Carcasses with higher FW or FP had less weight loss in steaks during cooking (-0.26 and -0.29). HCW, MW and MP were positively correlated with LDH (0.22 to 0.30); there were opposite signs for these three traits with ICDH (-0.08 to -0.21) and no correlation with HAD. Size and composition were not correlated with μ- or milli-calpain concentrations; there was a tendency for those with higher MW or MP to have lower CAST concentrations (-0.11 and -0.21), whilst those with higher FW and FP had higher CAST concentrations (0.17 and 0.19). Higher HCW, MW and MP were correlated with greater glycolytic potential (0.22, 0.21 and 0.05); BW and BP had correlations with GLYP of opposite sign to each other (0.14 and -0.15).

The three pH traits had very low correlations with each other (0.12 to -0.15). pHu had a correlation of 0.25 with average shear force, but only 0.08 with the half-life of fall in shear force. The only other correlation with a pH trait was pHu x glycorytic potential (-0.17), indicating that high glycogen reserves in cattle at slaughter were associated with lower pHu.

The two shear-force traits had a correlation of 0.48 between them, with the moderate value reflecting the coefficient of variation for SHLF. Neither trait was associated with weight loss in meat during cooking, nor with the three enzymes LDH, ICDH and HAD. Both shear-force traits were negatively correlated with μ-calpain (-0.27 and -0.14), and positively with CAST (0.26 and 0.28).

For the three enzymes LDH, ICDH and HAD, only ICDH and HAD were closely correlated (0.67). LDH had a correlation of -0.22 with PWL.

For the calpain system, μ-calpain and milli-calpain had a correlation of 0.33, and both were positively correlated with CAST (0.26 and 0.38).

DISCUSSION

Further details of breed-group differences in carcass composition were reported for this experiment by Morris *et al.* (2000a). The XL breed had higher HCW and MP, and lower FP and BP than the XJ breed. On a within-breed basis (Table 2), higher HCW was significantly associated with higher MP and FP and lower BP.

The tenderness of meat, as measured by shear force, is a highly variable attribute influenced by both animal characteristics and *post mortem* processing conditions. In particular, chilling can substantially affect the rate and extent of tenderisation and, for muscles held on the carcass, is difficult to control accurately because of differences in carcass weight and the performance of commercial chillers. Also, since the proteolytic events responsible for tenderisation begin at, or near, *rigor mortis* (George *et al*., 1980; Devine & Graafhuis, 1995), variation in the rate of *post mortem* pH-decline needs also to be considered. By removing the striploins after dressing and rapidly equilibrating the temperature to 15°C, temperature differences were minimised; then monitoring the pH decline to identify the time of *rigor mortis* ensured that the first shear force measurement was made at a functionally equivalent time point for each animal. By this methodology, we found that shear force values were not affected by muscle metabolic enzyme indicators (correlations ranging from -0.12 to 0.13). These included LDH, ICDH and HAD, enzymes that reflect the activity of, respectively, glycolysis, the tricarboxylic acid cycle and fatty acid oxidation. In

contrast, Zamora *et al.* (1996) found that high oxidative activity (citrate synthase) was associated with increased shear force, an effect also associated with increased red fibres (Whipple *et al.*, 1990) or type I fibres (Totland *et al.*, 1988). The constant temperature protocol and corrections for onset of the ageing process, taken to begin when ultimate pH was attained, may account for this difference. However, LDH did correlate with aspects of carcass composition, consistent with previous studies (Shackelford *et al.*, 1994; Renand *et al.*, 1995).

Calpains are considered to be the principal enzyme system involved in *post mortem* tenderisation. Calpain activity is reported to correlate with the extent of tenderisation (Koohmaraie *et al.*, 1987; Zamora *et al.*, 1996), though high levels of the calpain inhibitor are associated with increased toughness (Shackelford *et al.*, 1994; Zamora *et al.*, 1996; Wulf *et al.*, 1996). The present study confirms the role of both μ-calpain and its inhibitor CAST in the development of tenderness. It also suggests a role for CAST in muscle growth (Huang & Forsberg, 1998), as reflected in the correlation with MP.

Data from Table 2 confirm previous experiments with weight-selected and Control cattle, which have shown that muscles from the (heavier) selected-herd cattle had higher glycogen content (Morris *et al.*, 2000b), and these muscles were slightly more tender (Morris *et al.*, 1998) than those of Controls. The correlations between HCW or MW and GLYP in the present study were positive (0.22 and 0.21), showing that heavier carcasses and those carrying more muscle weight had higher GLYP. As with all the correlations shown (Table 2), regressions can be derived from the correlation coefficients and appropriate RSDs (Table 1). For example, a 10-kg increase in HCW was associated with a 4.22 lactate-equivalent increase in GLYP, or a 10% increase in HCW was associated with a 4.2% increase in GLYP.

We conclude that the correlations observed in the present study were generally consistent with findings published by other groups. The exception was pH1, pHu and pHf and their correlations with other traits, which are explained here in terms of our constant-temperature protocol; it is also noted for pHu that its standard deviation was very small. From correlation estimates with pH measures, the 3 enzymes, the calpain system, or GLYP, weights were only found to be associated with LDH and GLYP.

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