The use of double-muscled cattle breeds in terminal crosses: Meat quality

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Gariépy, C., Seoane, J. R., Cloteau, C., Martin, J. F. and Roy, G. L. 1999. **The use of double-muscled cattle breeds in terminal crosses: Meat quality.** Can. J. Anim. Sci. **79**: 301–308. The purpose of this study was to assess the quality of meat from 84 calves born from British (50% Hereford and 50% Red Angus) and Continental (50% Simmental and 50% Maine Anjou) dams inseminated with semen from normal (Charolais) or double-muscled (Piedmontese, Belgian Blue) sires. Lean composition of Belgian Blue and Piedmontese sired cattle had less intramuscular fat and more protein than Charolais sired cattle ($P < 0.01$ to 0.05). Breed of sire, origin of dam or calf sex had no effect on longissimus ultimate pH, thawing and cooking losses, shear forces, tenderness and overall flavour. However, meat from male progeny displayed higher drip loss ($P < 0.05$) and meat colour of male calves born from British dams was slightly more saturated than that of male calves born from Continental dams ($P < 0.02$). There were no other single effects of parental traits on meat quality. Significant interactions on total and soluble collagen content involving parental traits together with the single sex effect of the progeny ($P < 0.05$) did not induce textural differences, but meat from male progeny and that from Continental dams crossed with Belgian Blue sires was more juicy ($P < 0.05$). The use of DM bulls in terminal crosses resulted in increased lean yield and less marbling of the meat of the progeny but did not exert any other important effect on meat quality.

Key words: Beef, double-muscling, meat quality

Gariépy, C., Seoane, J. R., Cloteau, C., Martin, J. F. et Roy, G. L. 1999. **Utilisation des races à double musculature en croisements terminaux: qualité de la viande.** Can. J. Anim. Sci. **79**: 301–308. Le but de cette étude était d'évaluer la qualité de la viande de 84 veaux nés de mères des races anglaises (50% Hereford et 50% Red Angus) et continentales (50% Simmental et 50% Maine Anjou) inséminées avec la semence de taureaux normaux (Charolais) ou à double musculature (Piedmontais, Blanc Bleu Belge). Le muscle des veaux Blanc Bleu Belge et Piedmontais contenait moins de gras intramusculaire et plus de protéine que celui des veaux Charolais ($P < 0{,}01$ à 0,05). La race du père, l'origin de la mère et le sexe des veaux n'eurent aucun effet sur le pH ultime, les pertes à la décongélation et à la cuisson, les forces de cisaillement, la tendreté et la saveur globale du *longissimus dorsi*. Cependant, la viande de la progéniture mâle fut plus exsudative ($P < 0{,}05$) et la couleur de la viande des mâles issus des mères anglaises fut légèrement plus saturée que celle des mâles issus des mères continentales ($P < 0{,}02$). Il n'y eut aucun autre effet simple des caractères parentaux sur la qualité ultime de la viande. Des interactions significatives impliquant les effets parentaux ainsi qu'un effet simple du sexe de la progéniture furent identifiés sur les fractions totales et solubles du collagène ($P < 0{,}05$), mais n'induisirent aucune différence de texture de la viande. La viande de la progéniture mâle et celle provenant de mères Continentales croisées aux taureaux Blanc Bleu Belges furent cependant plus juteuses ($P < 0{,}05$). L'emploi des taureaux à double musculature lors des croisements terminaux augmente le rendement en maigre et diminue le persillage de la viande de la progéniture, mais n'influence pas de façon importante les autres caractéristiques sensorielles de la viande.

Mots clés: Boeuf, double musculature, qualité de la viande

Muscular hypertrophy or double muscling (DM) in cattle was identified almost 200 yr ago (Culley 1807). However, the bulk of information on this inherited condition has been mainly obtained during the last decades from comparisons between cattle showing double muscling and normal ones. There is no objective biological method available for the identification of the carriers of the most likely single gene that would be responsible for this condition (Arthur 1995). Upon subjective assessment of the musculature, hypertrophy is more prominent in the hindlimbs than in the forelimbs and large superficial muscles are more affected than deep muscles (Boccard and Dumont 1974). A list of physiological abnormalities associated with the syndrome has been reviewed by Swatland (1984). Among them, reduced fertility, dystocia and calf survival are the most important. In spite of these problems, consumer preferences for leaner

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Abbreviations: **B**, British; **BB**, Belgian Blue; **C**, Continental; **CH**, Charolais; **DM**, double-muscled; **FA**, fatty acid; **WHC**, water-holding capacity

meat and price paid to the producer for superior carcass yield have maintained the interest for DM cattle. Indeed, the syndrome has been associated with characteristics such as: higher meat yield, higher proportion of expensive cuts of meat and lean and very tender meat, as reviewed by Arthur (1995) who indicated that a premium is paid for this type of meat in European countries.

Muscular hypertrophy is mainly due to an increase in number of muscle fibers (hyperplasia) although an increase in fiber size (hypertrophy) has also been reported (Arthur 1995). According to Swatland (1984), a higher percentage of white muscle fibers could explain the paler appearance and reduced water-holding capacity and taste observed in DM meat (Boccard 1981, 1982; Bailey et al. 1982). Its superior tenderness would be attributable to a lower total and higher soluble collagen content (Boccard 1982; Bailey et al. 1982).

In order to take advantage of the assets associated with the DM syndrome while minimizing potential problems, Arthur (1995) has suggested the use of a terminal sire breeding system whereby normal females are mated to DM sires and all progeny slaughtered for commercial production.

Although a fairly large body of information is available on DM cattle, there are relatively few reliable data available on the performance of DM crossbreds. In addition to the character expression being influenced by breed, nutrition and sex (Ménissier 1982b), the large variation in performance among progeny of DM cattle crossed with normal ones complicates the picture. As reported by Arthur (1995), part of the progeny could be double-muscled, while the others could be normal or intermediates. Studies by Cundiff et al. (1993, 1994) have shown that carcass characteristics of DM cattle are expressed to some degree in the crossbreds. However, much less information is available on meat quality of DM crossbreds. Contrary to the superior meat tenderness generally attributed to DM cattle, there seems to be no differences in shear forces of meat from either DM or normal sired progeny when slaughtered at the same age (Tatum et al. 1990; Cundiff et al. 1994). In fact, as reviewed by Arthur (1995), higher meat yield of DM cattle has overshadowed its tenderness.

The purpose of this study was, therefore, to evaluate the overall meat quality from progeny of double muscled sires crossed with normal dams of British and Continental breeds.

MATERIALS AND METHODS

Animals

Semen from five sires of each of two DM breeds, namely Belgian Blue (BB) and Piedmontese (PM), and from five Charolais (CH) bulls exempt of the DM condition (controls) was used to inseminate two groups of normal hybrid dams: a British (B) group consisting of 50% Red Angus and 50% Hereford cows, and a Continental (C) group consisting of 50% Simmental and 50% Maine Anjou cows. These represent breeds commonly used in Quebec and Northern Ontario.

All calves were raised at the Agriculture and Agri-Food Canada Experimental Farm at Kapuskasing (Ontario) as described by Seoane et al. (1999). Briefly, calves were kept with their mothers until weaning at approximately 185 d of age. After weaning, all calves were implanted with Ralgro and placed in feedlots. Steers were fed in pens equipped with electronic head gates (American Calan® Inc., Northwood, NH), whereas the heifers were fed in groups and were separated according to the paternal breed. The diet fed during backgrounding consisted of ad libitum fed grass silage supplemented with 600 g canola meal plus 50 g of a mineral mixture. For the finishing phase, the same mineral pre-blend was used with a mixture of 35% rolled barley and 65% grass silage. All animals received the same diets and same management.

When ultrasound readings indicated approximately 10 mm of backfat thickness, including the skin, animals were transported to a provincially inspected slaughterhouse (Lorrainville, Temiscamingue, Quebec) located at 450 km from the experimental farm. Feed deprivation was 48 h but animals had free access to water during this period. They were killed and carcasses refrigerated under standard commercial procedures. After grading, carcasses were aged for 7 d before the short loins were taken. They were then frozen at –40°C for up to 22 wk under vacuum until meat quality analyses were performed.

Laboratory Analyses

The porterhouse steak was dissected into lean, fat and bone tissues and each was expressed as a percentage of the total weight of the steak. The lean was further liophylized and ground in a blender for analyses of intramuscular fat and protein. Protein was determined by the Kjeldahl procedure. Lipid extraction of intramuscular fat was conducted with a Soxtec system HT6 apparatus (Tecator) in accordance with the Association of Official Analytical Chemists (AOAC) (1995) using a chloroform:methanol (2:1) solution.

Cholesterol in meat was obtained by the hexane extraction method of Van Elswyk et al. (1991) with the following modification. The hexane layer was dried directly using a rotary evaporator. The cholesterol residue was then dissolved using 5 mL of hot acetonitrile and placed into siliconized, teflon-capped tubes for analyses. Cholesterol was analyzed by high performance liquid chromatography according to the procedure of Goh et al. (1989).

Individual fatty acids were determined after transesterification with sodium methoxyde using the GLC technique described by Chouinard et al. (1997). Determinations were carried out under the following conditions: HP 5890 chromatograph (Hewlett-Packard Co., Palo Alto, CA), 60 m × 0.32 mm DB-23 capillary column, 0.25-µm film thickness, H_2 carrier gas, 2.73 cm^3 min^{-1} volumetric flow rate, injector split 1/72.26 at 250°C, septum purge vent at 2.7 mL min^{-1}, flame ionization detector at 250°C, and 15 kPa head pressure. The initial temperature was 150ºC, which was increased 5°C min^{-1} up to 200°C and maintained at that temperature for 7 min. Peak area was measured using a Nelson Analytical system (PE Nelson, Cupertino, CA). Each peak was identified using methyl ester standards (Alltech, Deerfield, IL) on the basis of their retention times. The surface to concentration ratio for all identified FA was used to determine their respective concentrations (Chouinard et al. 1997).

For quality measurements, five 2.5 cm steaks were obtained in the frozen state from the anterior portion of the

longissimus lumborum. Two steaks were maintained frozen (–30°C) under vacuum until ulterior sensory evaluation. Two other steaks were used for duplicate measurements of pH, colour and thaw and drip losses. The remaining steak was used for total and soluble collagen determination. A 10-cm sample was obtained in the frozen state from the mid portion of the longissimus lumborum for shear force measurements. Samples for physicochemical analyses were thawed at 4°C for 48 h. Difference in weight of steaks before and after thawing was used for the calculation of thawing loss as percent of the initial weight. Other measurements were all carried out on thawed samples.

Duplicate pH measurements were taken with a spear type electrode (model 406-M6, Ingold, Wilmington, MA) connected to an Oakton portable pH meter (Vernon Hills, IL). Surface L^*, a^* and b^* colour indices were obtained in duplicate after a 1-h blooming period at 4°C with a Chroma Meter II (Minolta, Mississauga, ON). Hue and saturation were calculated according to the formulas $\text{Tan}^{-1}\ b^*/a^*$ and $(a^{*2} + b^{*2})^{0.5}$, respectively. Steaks were then placed on a grid at 4°C and weight difference after a 48-h period was used for the calculation of percent drip loss.

From the larger longissimus sample, a 5 cm × 4 cm × 6 cm (length × width × height) sub-sample was prepared for shear force measurement. Individual sub-samples were placed in polyethylene bags and a slight vacuum was applied to allow good heat transfer. Before cooking, all samples were equilibrated at 4°C for 2 h. They were then cooked in a water bath maintained at 68°C for 32 min. At the end of the cooking period, samples were cooled for 1 h under cold running water until a final internal temperature of 68°C was obtained. These conditions were determined during preliminary trials and were monitored with thermocouples. This internal temperature was chosen to compare shear force measurements with results of sensory evaluation. Weights of the raw and cooked samples were used for the calculation of percent cooking losses. Cross sectional cooked sticks (1 cm^2) were prepared with their length parallel to the fibre axis. They were sheared with a Warner-Bratzler device connected to a texturometer (model 4201, Instron Corp., Canton, MA) according to Moller (1981). Fifteen readings were taken per sample.

Insoluble and soluble collagen were measured respectively on two 4-g and on one 50-g meat samples in order to obtain two aliquots for ulterior acid hydrolysis. Samples in the semi-frozen state were finely chopped with a scalpel in order to allow complete hydrolysis. All the samples were individually vacuum packaged before being equilibrated and cooked under the same conditions as used for shear force measurements. A final internal temperature of 68°C was attained to correspond with the final temperature of the roasts used for sensory evaluation. This dry cooking procedure was based on the method suggested by Williams and Harrison (1978) for the assessment of correlations between collagen determination, shear force measurements and tenderness of expensive cuts of meat. Cooked samples were cooled under cold running water. For insoluble collagen determination, cooking juice was discarded and samples were blotted with absorbant paper in order to avoid contamination with solubilized collagen at the surface. Alternatively, measurement of soluble collagen content was carried out on the cooking juice from the largest sample. A 10-min centrifugation (1000 × *g*, 20°C) was used to eliminate fat and cell materials. All samples were hydrolysed for 16 h at 105°C under acid conditions (H_2SO_4, 7 N) and hydroxyproline was determined according to method # 990-26 of the AOAC (1995). Total collagen content was calculated as the sum of the soluble and insoluble fractions and was expressed as mg g^{-1} in DM basis. Soluble collagen was expressed as percentage of total collagen.

Sensory Analyses

Sensory evaluation of tenderness, juiciness and off-flavour was carried out on steaks cooked at 177°C for 30 min in a preheated convection oven until a final internal temperature of 68°C was reached as monitored with thermocouples. Cubes of 1.5 cm were prepared and maintained in hermetic glass jars for equilibration at room temperature. In order to evaluate any possible interactions, the 12 combinations of treatments were assessed within each session. For each treatment, three different animals were evaluated and this entire protocol was repeated twice. Six sessions were therefore necessary and 36 animals were evaluated. A trained panel of eight members evaluated the intensity of each attribute on a computerized 15 cm semi-structured line scale (version 4.1, Compusense Inc., Guelph, ON) for juiciness and tenderness, with the left end of the scale representing zero stimulus and the right end corresponding to a strong level of perception for the attribute. Spectrum ™ terminology (Meilgaard et al. 1991) was used as a reference standard for juiciness and tenderness. The evaluation of off-flavour was done with a 10 cm structured line scale with marks for absent, slight, moderate and high levels.

Statistical Analyses

For the physico-chemical parameters, the ANOVA was carried out using the MIXED procedure of SAS Institute, Inc. (1998) according to the following model:

$$Y_{ijklm} = \mu + B_i + F_j + (BF)_{ij} + S_k + (BS)_{ik} + (FS)_{jk} + (BFS)_{ijk} + P_l(B_i) + e_{ijklm}$$

where Y_{ijklm} is the individual observation of the *m*th animal of the *l*th sire (*P*) of the *i*th breed (*B*), the *j*th dam origin (*F*), the *k*th sex of the progeny (*S*) and μ is the overall mean. $P_l(B_i)$ corrects for the effect of calves born from the same sire. All main effects were fixed except for $P_l(B_i)$ and the error e_{ijklm}, which were independent random variables.

For sensory parameters, a Generalized Procrustean Analysis (Gower 1975) was first carried out in order to evaluate the level of consensus existing among judges with respect to sensory attributes. This method allows for the measurement of how judges comprehend the different attributes and use the scales. Procrustean ANOVA was then carried out on results from concurring judges using the GLM procedure of SAS Institute, Inc. (1989).

Table 1. Effects of crossing normal or double-muscled sires with British or Continental dams on meat composition of the progeny (main effects)[z]

	Breed of sire			Origin of dam		Sex of calf		
Parameter	Charolais	Piedmontese	Belgian Blue	British	Continental	Male	Female	SEM[y]
Total porterhouse steak								
Lean (%)	62.3*bT*	66.1*a*	65.5*a*	63.8	65.5	64.8	64.5	0.62
Dissectable fat (%)	19.5*aT*	17.0*b*	16.8*b*	18.1	17.4	17.3	18.2	0.45
Bone (%)	18.2	16.9	17.7	18.2	17.1	17.9	17.3	0.52
Lean composition (fresh basis)								
Water (%)	70.5	71.0	71.5	70.7*bT*	71.2*a*	70.9	71.1	0.14
Protein (%)	22.8*b**	23.2*a*	23.4*a*	23.1	23.1	23.2	23.1	0.08
Fat (%)	5.6*a***	4.6*b*	4.1*b*	5.0	4.5	4.8	4.7	0.16
Cholesterol (mg 100 g^{-1})	59.0	59.4	59.8	59.4	59.4	59.6	59.1	0.36

[z]Least-square means. For a given parameter within a main effect, means followed by a different letter are significantly different (*T* = tendency: $P < 0.10$, * = $P < 0.05$, ** = $P < 0.01$).
[y]Standard error of the mean.

Table 2. Effects of crossing normal or double-muscled sires with British or Continental dams on fatty acid profile of intramuscular fat of the progeny (main effects)[z]

	Breed of sire			Origin of dam		Sex of calf		
Fatty acid (%)	Charolais	Piedmontese	Belgian Blue	British	Continental	Male	Female	SEM[y]
Less than C14	0.22	0.20	0.22	0.22	0.21	0.20*b***	0.22*a*	0.00
C14:0	3.35	3.20	3.47	3.36	3.33	3.25	3.44	0.05
cis-C14:1	0.57	0.55	0.53	0.54	0.56	0.52	0.58	0.02
C15:0	0.60	0.57	0.66	0.61	0.61	0.62	0.60	0.01
C16:0	31.7	31.0	31.5	31.5	31.3	31.2	31.6	0.17
trans-C16:1	0.17	0.19	0.20	0.18	0.20	0.19	0.18	0.00
cis-C16:1	2.83	2.81	2.81	2.67*b**	2.95*a*	2.74	2.89	0.06
C17:0	0.60	0.59	0.62	0.60	0.61	0.62	0.60	0.01
C18:0	17.0	17.0	17.3	17.4	16.8	17.4	16.8	0.21
trans-C18:1	2.48	2.40	2.57	2.50	2.46	2.65*a***	2.32*b*	0.06
cis-C18:1	38.4	39.5	37.6	38.2	38.8	38.6	38.4	0.25
trans-trans-C18:2	0.57	0.52	0.52	0.55	0.52	0.55	0.52	0.02
C18:2	1.18	1.26	1.29	1.19*b**	1.29*a*	1.25	1.23	0.02
C18:3	0.28	0.29	0.31	0.29	0.30	0.31*a**	0.28*b*	0.01
C19:0	0.07	0.06	0.07	0.07	0.06	0.07	0.07	0.00
Saturated	53.5	52.4	54.3	53.9*a**	52.9*b*	53.2	53.6	0.26
Unsaturated	46.5	47.5	45.8	46.1*b*	47.1*a**	46.8	46.4	0.26

[z]Least-square means. For a given parameter within a main effect, means followed by a different letter are significantly different (* = $P < 0.05$, ** = $P < 0.01$).
[y]Standard error of the mean.

RESULTS AND DISCUSSION

Carcass Traits and Meat Composition

Dissectable lean from the porterhouse steak tended to be higher ($P < 0.10$; Table 1) and dissectable fat lower ($P < 0.10$) in calves sired by DM than in those sired by CH bulls. These results are in agreement with those published in the literature (Arthur et al. 1989). Differences in bone percentage were not statistically different. Analysis of the longissimus and psoas muscles revealed more protein ($P < 0.05$) and less intramuscular fat ($P < 0.01$) in progeny of DM sires than in that of CH sires. Cholesterol concentrations averaged 59.4 mg 100 g^{-1} of lean and were not affected by sire, dam or sex of the calf. Baker and Lunt (1990) reported cholesterol values of 57.7 and 55.2 mg 100 g^{-1} of lean for PM and CH sired cattle, respectively, values similar to those obtained in the present study.

Intramuscular fat (Table 2) was rich in *cis*-C18:1 (38.5%), C16:0 (31.4%) and C18:0 (17.1%) fatty acids, which represent normal values for steers consuming conventional finishing diets (Camfield et al. 1997). Camfield et al. (1997) observed that C18:0 content decreased from 17.6 to 12.5% as the time on a finishing 85% concentrate diet increased from 0 to 90 d. Breed of sire did not have any effect on FA composition of intramuscular fat (Table 2). Calves of British dams had less *cis*-C16:1, C18:2 and total unsaturated FA than calves from Continental dams ($P < 0.05$).

Meat pH, Color and Water Losses

Pre-slaughter procedures and treatments used in this study had no effect on meat ultimate pH (Table 3), which varied within the normal range occurring in beef longissimus muscle according to Asghar and Pearson (1980). Although DM animals have been reported to be, on a general basis, more stress sensitive than controls (Menissier 1982a), our results indicate that crossbred DM cattle can sustain a fairly long transportation period (450 km) without suffering any major muscular energy expenditure. As a consequence, there were no differences in *L** values (Table 3) which are known to be pH dependant and no dark cutters were obtained. Arthur (1995) and Bailey et al. (1982) have reported a paler appearance of meat from DM cattle, which was attributed to a

Table 3. Effects of crossing normal or double-muscled sires with British or Continental dams on pH, colour and water losses of the longissimus dorsi of the progeny (main effects)[z]

		Meat colour					Water losses (%)		
Main effects	pH	*L**	*a**	*b**	Hue	Saturation[y]	Thawing	Drip	Cooking
Breed of sire									
Charolais	5.66	38.66	18.26	9.71	27.86	20.47	1.66	6.62	19.41
Piedmontese	5.56	38.69	17.64	9.59	28.40	20.08	2.04	6.81	20.00
Belgian Blue	5.66	37.69	16.57	8.75	27.62	18.77	1.77	6.18	19.39
Origin of dam									
British	5.65	38.49	17.77	9.61	28.12	20.22	1.76	6.43	19.30
Continental	5.61	38.20	17.21	9.10	27.81	19.33	1.89	6.64	19.90
Sex of calf									
Male	5.64	38.70	17.22	9.18	27.74	19.53	1.93	7.22*a*	20.01
Female	5.62	37.99	17.77	9.52	28.19	20.02	1.72	5.85*b*	19.19
SEM[z]	0.02	0.35	0.27	0.22	0.33	0.31	0.11	0.28	0.42

[z]Least-square means. For a given parameter within a main effect, means followed by a different letter are significantly different ($P < 0.05$).
[y]There was a significant dam – sex-of-calf interaction. Meat colour of males born from British dams was more saturated than that of males born from Continental dams ($P < 0.02$).
[z]Standard error of the mean.

Table 4. Interactive effects of crossing double-muscled sires with British or Continental dams and single sex effect on collagen, shear force and juiciness of the longissimus lumborum of the progeny[z]

	Collagen content			
Main effects	Total (mg g^{-1} DM)	Soluble[y] (% of total)	Shear force[x] (kg)	Juiciness[w]
Breed of sire × dam combination				
Charolais × British	11.95 ± 0.62*ab*	1.67 ± 0.13*ab*	5.94 ± 0.32*ab*	2.71 ± 0.11*b*
Charolais × Continental	11.66 ± 0.57*ab*	1.58 ± 0.12*ab*		2.80 ± 0.11*b*
Piedmontese × British	10.96 ± 0.59*b*	1.48 ± 0.13*b*	5.56 ± 0.34*b*	2.77 ± 0.11*b*
Piedmontese × Continental	11.18 ± 0.67*ab*	1.87 ± 0.15*aT*		3.02 ± 0.11*ab*
Belgian Blue × British	12.92 ± 0.61*a**	1.78 ± 0.13*ab*	6.45 ± 0.34*aT*	2.47 ± 0.11*b*
Belgian Blue × Continental	10.45 ± 0.65*b*	1.62 ± 0.14*ab*		3.23 ± 0.11*a**
Sex of calf				
Male	11.06 ± 0.37*b*	1.87 ± 0.08*a***	6.14 ± 0.28	2.98 ± 0.07*a**
Female	11.99 ± 0.35*a**	1.46 ± 0.08*b*	5.83 ± 0.25	2.65 ± 0.07*b*

[z]Least-square means ± standard error. Means within a parameter followed by a different letter are statistically different ($T = P < 0.10$, * = $P < 0.05$, ** = $P < 0.01$). There was no sire, dam or sex effect on sensory evaluation of tenderness (3.94 ± 0.16) and off flavour (0.92 ± 0.21).
[y]Interaction of breed of sire and origin of dam tended to be significant ($P < 0.07$).
[x]Interaction of breed of sire and origin of dam was not statistically significant; values reported represent breed of sire effect ($P < 0.08$).
[w]Juiciness was assessed with a semi-structured line scale varying from 0 to 15. A higher score indicates a more pronounced characteristic.

higher glycolytic fibre content. In our study, however, breed of sire had no effect on both *a** and *b** values and, as a consequence, no differences were found in both hue and saturation (Table 3). A significant interaction between origin of the dam and calf sex was obtained on *a** values, which led to a difference in colour saturation ($P < 0.02$). According to this interaction, meat colour of steers born of British dams (20.70 ± 0.65) was more saturated ($P < 0.02$) than meat of steers born of Continental dams (18.36 ± 0.71). However, absence of any single dam and calf sex effects on both *a** and *b** values (Table 3) indicates that this interaction is of small magnitude relative to the human eye.

With respect to WHC, treatments had no effect on thawing and cooking losses (Table 3). However, meat from male progeny displayed higher drip loss than that from females ($P < 0.05$) irrespective of sire or dam, which had no effect on this parameter (Table 3). Absence of any effect of treatments on pH or thawing losses cannot support the lower WHC of meat from male progeny. As presented in Table 1, there was also no effect of calf sex on water or fat content of the longissimus muscle from these animals.

Collagen Content, Shear Force and Sensory Evaluation

A lower total collagen content was obtained for the meat from male progeny (Table 4) and could relate to its lower WHC. As reported by Hamm (1960), it is common opinion that the WHC of meat increases with the amount of connective tissue it contains. It must be pointed out that this opinion, however, was mainly based on experiences obtained from heating procedures such as in processing emulsion type sausages. From a histological study, however, Offer and Knight (1988) have demonstrated that rigor development causes a first fluid-filled gap at the perymisium level followed by a second extra-cellular space at the endomysium level upon rigor completion. This indicates that water can

pass relatively easily through both cell membrane and the thinner endomysium layer but the gap observed at the perimysium junction also suggests a barrier effect brought about by heavier connective tissue strands. According to Asghar and Henrickson (1982), collagen associated mucopolysaccharides could also contribute to WHC of animal tissue. In addition to its smaller amount in total collagen, meat from male progeny also had a larger portion of soluble collagen ($P < 0.01$; Table 4). According to Etherington (1987), both the quantity and the degree of crosslinking of intramuscular collagen can be influenced by the age of an animal. Although, Seoane et al. (1999) did not find any difference in age at slaughter between male and female progeny, they did report significantly higher carcass weight and average daily gain in males, which could explain their lower total and higher soluble collagen content. According to Menissier (1982b), males tend to manifest more clearly muscular hypertrophy which, as suggested by Boccard (1982), would depend on inferior intramuscular collagen content that would allow superior muscular development. Indeed, absence of any difference between males and females of the CH progeny in this study clearly demonstrates that the lower intramuscular collagen content in males, arose from DM sire breeds (results not shown since calf sex × sire breed interaction was not significant). Changes in connective tissue in meat from fast-growing animals may in part be derived from a small overall decrease in the percentage of total collagen, but it seems more likely that the large quantity of recently synthesized and poorly cross-linked collagen, which represents its soluble fraction, is diluting out the older fibres (Etherington 1987).

Single effects for sire and dam were not significant on either total or soluble collagen content. On this basis, progeny from either DM breeds or controls would have similar connective tissue characteristics, contrary to what has been documented in the literature from comparisons between animals showing or not the DM condition (Bailey et al. 1982; Boccard 1982; Hanset et al. 1982). The ANOVA, however, revealed a significant interaction of the parental traits on total collagen content ($P < 0.05$) and also, at a lower probability level ($P < 0.07$), on the soluble collagen fraction of meat from the entire progeny. These interactions would be caused, in the case of total collagen, by the much larger difference found in the progeny of dams of different origin sired with BB (Table 4). In the case of soluble collagen content, the interaction arose from the opposite pattern found between dam origin according to the sire breed used. In other words, in comparison with CH progeny, collagen solubility of meat from DM sires progeny would be much more influenced by the origin of the dam (Table 4). The soluble collagen fraction was also under a significant interactive effect of calf sex and dam. Meat from males born of Continental dams had more soluble collagen than females (2.00 vs. 1.37% respectively; $P < 0.03$). Offsprings of British dams were in intermediate position and did not statistically differ.

These preceding interactions, however, did not translate into textural differences as there was no significant effect of treatments on either shear force measurements (Table 4) or sensory assessment of tenderness. In this study, meat quality from the entire progeny was evaluated and the possible varying expression of treatment among the progeny might be thought of as a cause for the lack of tenderness differences as objectively and subjectively evaluated. In both cases, however, the variation associated with shear force measurements and tenderness assessment, respectively, was well within the range commonly encountered in the literature. Results by Gariépy et al. (1990) indicated that a difference of 1 kg in shear forces between beef samples obtained following the procedure of Moller (1981) was in the order of detectable magnitude by a trained panel. It should be pointed out that, although non-significant, there was a marked difference on shear force values between samples from the two DM sire breeds (5.56 and 6.45 kg for PM and BB, respectively; $P = 0.08$; Table 4). A similar ranking was obtained by Liboriussen (1982) with meat from the progeny of the same sire breeds. In that particular study, the difference in shear forces between samples was also not statistically significant, but the panel found that meat from BB progeny was significantly tougher than that from both CH and PM with an overall preference for meat from PM with respect to that from BB. Also similar to our results, meat from CH progeny was found in an intermediate position. Uytterhaegen et al. (1994) have reported increased toughness in meat from DM Belgian Blue that was due to their reduced postmortem proteolytic tenderization in comparison with normal Belgian Blue. It must be mentioned that the dry cooking procedure (Williams and Harrison 1978) yields smaller amounts of soluble collagen than the salt, acid or alkali solution extraction procedures (Light 1985). This procedure, on the other hand, has potential to favour the establishment of relationship with shear forces. According to Eilert and Mandigo (1993), the solution extraction procedures, along with the higher cooking temperature involved, may indeed lead to a solubilization artifact and impede correlations with textural measurements. Notwithstanding this procedure and the fact that treatment had no effect on shear forces and tenderness evaluation, juiciness was influenced by calf sex ($P < 0.05$) and also by the same interaction of parental traits, which influenced total and soluble collagen contents. Meat from male progeny was more juicy than that from females (Table 4) and the effect of Continental dams, which also increased juiciness of DM crossbreds, was much more prevalent when crossed with BB sires. We have not found any information on the relationship between collagen solubility and meat juiciness but the influence of the soluble collagen fraction on retention or release of juice during chewing appears as a logical possibility since the largest amount was found in meat from male progeny (Table 4). However, a closer look at the results suggests a more effective role of the total collagen content as the smallest amount was also found in meat from male progeny with respect to that from female, but also because meat from Continental and British dams crossed with BB sires induced the most and less juicy meat, respectively (Table 4). This aspect is also in agreement with the observations of Offer and Knight (1988) on the effect of the layers of connective tissue on

water migration within muscle as discussed previously. Since cooking losses were not affected by treatments, it is not clear how meat from male progeny, which displayed higher drip losses, could still be perceived as more juicy in the absence of any sex effect on intramuscular fat and water content as reported earlier. Since calf sex had minor effects on fatty acid profile (Table 2), it might simply be that the amount of drip released could not induce significant changes in juiciness rating. In spite of the reduced taste attributed to meat from DM cattle (Bailey et al. 1982), treatments in this study had no effects on the flavor of meat from the progeny.

CONCLUSION

Meat quality of progeny from normal British or Continental dams crossed with either DM or normal sires was evaluated. Carcasses of DM crosses tended to have more lean and their meat had less intramuscular fat than CH crosses. There were no single effects of either sire breed or dam on any ultimate meat quality parameters. Significant interactions involving parental traits and sex of the progeny were identified on soluble collagen content, but these did not result in significant textural differences in terms of shear forces and tenderness. However, meat from male progeny and that from the offspring of Continental dams crossed with BB sires, which had lower collagen content, were juicier. Therefore, the effect of DM as paternal trait on the overall meat quality of the progeny was rather minimal and depended on the origin of the dam and sex of the offspring. For commercial production, the decision whether or not to include DM as sires for terminal crosses must be based on criteria such as carcass yield of the progeny and consummer preferences for leaner meat.

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