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Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat content

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Abstract

Meat quality and marbling properties of Angus, Simmental, Charolais and Limousin steers (4×16) were compared at an average intramuscular fat content (IMF) of 3.25% in the *M. longissimus dorsi*. The steers were fattened on a forage-based diet until the desired, ultrasonically estimated IMF content was reached which resulted in considerably different growth and carcass characteristics. The Angus group showed a growth rate similar to Simmental and Charolais while Limousin grew slower, became oldest and provided the heaviest carcasses and best conformation. Angus carcasses showed the lowest weight but the highest fatness score. Marbling was equal for all breeds. Angus and Charolais provided pale meat with low haem iron content. Angus and Limousin beef was more tender on sensory assessment than Simmental beef, corresponding to differences found in shear force (non-significant) and myofibrillar fragmentation index measured at 48 h post mortem. Flavour was similar among breed groups while juiciness was highest for Limousin and lowest for Angus. The juicier beef simultaneously showed the highest drip but the lowest cooking losses. In conclusion, clear differences in meat quality were observed between breeds despite similar IMF contents.

Keywords: Beef; Steers; Breed; Meat quality; Intramuscular fat

1. Introduction

Meat quality of beef breeds has been measured and compared in numerous studies. These comparisons, however, mostly concentrated on potential breed differences at a similar age, length of fattening period, weight, or fatness score of the animals. Only a few studies have investigated meat quality of different breeds at the same intramuscular fat (IMF) content or marbling score (Tatum, Gronewald, Seideman, & Lamm, 1990; Wheeler, Cundiff, Koch, & Crouse, 1996). However, this was after statistical adjustment of the means, providing only an estimation and assuming a linear relationship between traits, which may not reflect the actual situation, and not by actually fattening cattle until a similar IMF content was achieved, probably because of the difficulty of accurately estimating IMF in live animals. Cattle breeds clearly differ in their capacity for IMF retention and, consequently, breed differences in age and weight are expected to be large when animals are fed on a similar energy level and slaughtered at the same IMF content (Koch, Dikeman, Allen, May, Crouse, & Campion, 1976; Koch, Dikeman, & Crouse, 1982; Koch, Dikeman, Jerry Lipsey, Allen, & Crouse, 1979). The influence of IMF content on beef palatability has often been discussed but its quantitative importance is controversial (Dikeman, 1996; Lusk, Fox, Schroeder, Mintert, & Koohmaraie, 1999). Nevertheless, the visual appearance of IMF, commonly called marbling, is the primary criterion for quality grading of beef carcass quality in the United States and Canada (Dubeski, Aalhus, Jones, Robertson, & Dyck, 1997). Moreover marbling is often linked with beef palatability by consumers and can therefore play an important role in purchasing decisions. A focus on marbling is especially important in some branded beef programs where a minimum amount and a fine distribution of IMF is defined or demanded (AAA, 2001).

The objective of the present study was to compare the meat quality of one early and three later-maturing

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breeds fattened to the same IMF content under controlled conditions in order to quantify the residual differences in marbling and meat quality.

2. Materials and methods

2.1. Experimental design

The experiment was carried out with Angus, Simmental, Charolais and Limousin steers originating from suckler herds and 13, 13, 11 and 15 different sires, respectively. All animals were purebred, except Angus (75% Angus blood on average). They entered the trial at an average age (±SD) of 238±25 days and were fattened in two consecutive and separate series. The first series was carried out in a tie-stall barn and the second series in a loose housing system with straw bedding (breed groups mixed). During the whole fattening period the animals had ad libitum access to the same diet consisting of maize silage, 520 g, grass silage, 260 g, and concentrate, 220 g per kg of dry matter (DM), a medium energy density diet (11.2 MJ metabolizable energy/kg DM; 135 g crude protein/kg DM) representing a typical semi-intensive European-type of fattening. The animals were assigned to slaughter when the IMF content, estimated by a real-time ultrasound scanner 200 and an integrated software prediction program (Pie Medical, Maastricht, Netherlands), reached the target level of between 3 and 4% (Chambaz, Morel, Scheeder, Kreuzer, & Dufey, 2001). However, as a certain inaccuracy of this assessment had to be taken into account (Chambaz, Dufey, Kreuzer, & Gresham, 2002), 12 animals per breed and series were fattened to be able to select post mortem on the basis of the chemically determined IMF content the eight animals per breed and series, which matched the requirements in IMF content best (similar target content and variation within breed).

2.2. Experimental procedures performed at slaughter

On the day of slaughter, animals were weighed and transported 60 km to a commercial slaughter plant and slaughtered within 4 h of departure from the research station. Hot carcass weight was recorded at about 1 h post-mortem (p.m.). Carcasses were chilled for 48 h at 2 °C. Measurements of pH and temperature were performed at 1, 3 and 48 h p.m. in the *M. longissimus dorsi* (LD) at the 10th rib with a portable pH meter (WTW 197S, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) equipped with a Sensor EB4 pH probe (Wintion, Gerzensee, Switzerland) and temperature probe (TFK 150/E, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany). At 48 h p.m. subcutaneous fat thickness was measured as described by Boggs, Merkel, and Doumit (1998), i.e. at three quarters of the width of the LD from the backbone between the 12th and the 13th rib.

The left carcass side was cut between the nineth and the 10th rib, and the so-called first category cuts, i.e. striploin, tenderloin and rump were prepared. Starting at the cranial part, the LD was cut into slices first removing approximately 300 g for chemical analyses (fat and collagen) after lyophilization and homogenization, followed by three 2 cm thick slices for later determination of drip loss, cooking loss, Warner-Bratzler shear force (WBSF) and sensory evaluation. Finally, three 1 cm thick slices were obtained for measurements of marbling traits, haem iron content, sarcomere length and myofibrillar fragmentation index (MFI). Samples were vacuum-packaged and frozen at −28 °C either directly or after an additional ageing period of 12 days at 2 °C which was applied for a second determination of MFI and for analysis of meat colour, WBSF and sensory evaluation.

2.3. Determination of intramuscular fat content and marbling

The IMF content was analysed using petroleum ether extraction (SLB, 1969). In order to objectively quantify marbling traits, intramuscular fat of the intact slice was chemically stained according to Albrecht, Wegner, and Ender (1996). Briefly, the LD was soaked for 7 days in a formol calcium solution, then in a solution of oil red (0.5 g oil red dissolved in 100 g isopropanol) for 7 h, followed by 4 h of washing in a 70% isopropanol solution with agitation. With this method it was possible to distinguish IMF from collagen and to intensify the contrast between IMF and other components of the LD. A digital photo image of the stained slice was then captured by a computer assisted video camera. Marbling traits were evaluated by an image analysis software (analySIS, Soft Imaging System GmbH, version 1999, Münster, Germany). Variables obtained in each sample were: visible fat as a percentage of total muscle area (entire cross section of LD and quarters: dorsal-medial, dorsal-lateral, ventral-medial and ventral-lateral), average fat particle size, number of fat particles per cm^2, the proportion of the total fat area in the three largest fat particles, and the number of particles >30 mm^2. All measurements were carried out separately in each quarter of the cross-section of the LD. The coefficient of variation of visible fat proportion among quarters within steers was calculated.

2.4. Analysis of meat quality

Meat colour traits (L^*, a^*, b^*) were determined without blooming in the raw LD with the Chroma-Meter CR-300 (Minolta, Osaka, Japan) applying the light source D65. Haem iron was analysed as pigments

(assuming 9.06% haem iron in pigment) according to the method of Barton (1967). Pigments were extracted with acetone and measured photometrically (640 nm, Lambda 2 spectral photometer, Perkin-Elmer, Überlingen, Germany).

Drip loss was quantified as described by Honikel (1998). Cooking loss was determined by weighing the samples before and directly after cooking. For this purpose frozen vacuum-packaged LD slices were thawed during 24 h at 2 °C and were stored for 1 h at room temperature before cooking. The slices were then broiled for 5 min on a grill (type BF-50, Beergrill AG, Zurich, Switzerland) at 195±5 °C by direct radiant heat with the samples being turned twice. The grill plate was directly connected to an external electronic thermoregulator (Ematherm A, Trafag AG, Männedorf, Switzerland) to minimize temperature variations. According to preliminary assessments, this procedure resulted in a meat core temperature of approximately 68 °C.

For shear force determinations on the original Warner-Bratzler device (model 3000, G-R Electric MFG Co, Manhattan, Kansas, USA), the cooked samples were cooled to ambient temperature. Ten cores of 1.27 cm diameter per sample were obtained parallel to the fibre orientation with an electrical drill (Kastner & Henrickson, 1969). The cores were obtained and always sheared in the same order beginning with the five dorsal cores followed by five ventral cores starting from the medial end of the slice. The mean WBSF values of the cores 1 and 2, 4 and 5, 6 and 7, and 9 and 10, respectively, were combined to describe the positions dorsal-medial, dorsal-lateral, ventral-medial and ventral-lateral.

Two replicates of 0.5 g, taken from the centre of the raw LD, were analysed for sarcomere length (Pospiech & Honikel, 1987). The samples were homogenized for 30 s with an Ultra-Turrax T25 (Janke & Kunkel, IKA Labortechnik, Staufen, Germany) at 9500 rpm in 5 ml borate buffer (0.1 M KCl, 0.039 M sodium tetraborate decahydrate and 5 mM EDTA, pH 7.1). The length of five consecutive sarcomeres was measured 12 times per replicate (in total equivalent to 120 determinations per animal) using an optical microscope (Olympus BX50, Olympus Optical Co, Tokyo, Japan) and the same image analysing software as for marbling.

The MFI was analysed in raw LD as described by Culler, Parish, Smith, and Cross (1978). The protein concentration of the suspension produced with this method was determined by the Biuret method (Gornall, Bardawill, & David, 1949). After dilution of the myofibril suspension to a concentration of 0.5±0.05 mg/ml, the final protein concentration was controlled using the micro-Biuret method (Bailey, 1967). The MFI is equivalent to the absorption value of the myofibril suspension, measured at 540 nm and multiplied by 200.

The collagen content (hydroxyproline×8) was measured in lyophilized LD as described by Arneth and Hamm (1971) and adapted to the Autoanalyser II chain (Technicon, Plainfield, New Jersey, USA). Collagen hydrothermal solubility at 90 °C was determined as outlined by Kopp, Sale, and Bonnet (1977).

2.5. Sensory evaluation

Sensory analysis was performed by an eight member, in-house trained panel. Panellists simultaneously assessed four samples, cooked as described for cooking loss, which were served hot on pre-warmed plates. Samples were from one representative of each breed provided in an arrangement which minimized the variation of IMF content within each session. Panellists were asked to judge the samples on 8-cm unstructured line scales anchored at each end with the descriptors very tough/tender, very slight/strong, very dry/juicy, very much disliked/liked for tenderness, flavour intensity, juiciness and preference, respectively. The marks of the panellists on the line scales were then converted to numbers by measuring the position of each mark with a computer-assisted FIZZ digitizer (version 1.30, Biosystemes, Couternon, France).

2.6. Statistical analysis

Data were statistically analysed with the NCSS program (version 1997, Hintze, Kaysville, Utah, USA) by analysis of variance. The model included breed and series as fixed effects, the interaction of these effects, and IMF as a covariate. The analysis of the sensory traits additionally considered the effects of panel session, panellists and IMF group as block nested within series. The Tukey method was applied for multiple comparison among breed group means considering $P<0.05$ as significant. The tables give the least square means, the standard error of the mean (SEM) and the level of significance of the effects and interactions.

3. Results

Fattening the steers of the different breeds under the same conditions and to a similar IMF content resulted in significant differences between breed groups in most growth and carcass traits (Table 1). The fattening period of the Angus group was only 0.53, 0.50 and 0.41 of that of the Simmental, Charolais and Limousin groups, respectively. The Limousin steers had a 13–21% lower growth rate compared with the other breed groups. Carcasses of Charolais and Limousin were significantly heavier than those of the Simmental and particularly of the Angus steers. Simmental and Angus had the lowest conformation scores, dressing percentage and proportion of first category cuts, both of which were highest in the Limousin. However, breed groups did not

Table 1
Growth and carcass traits of the selected steers fattened to a similar intramuscular fat content[a]

Variables	Angus	Simmental	Charolais	Limousin	SEM	*P*-values		
						Breed	Series	Breed×Series
N	16	16	16	16				
Age (days)	381c	499b	513b	594a	16.6	0.000	0.604	0.479
Fattening period (days)	141c	267b	281b	346a	16.3	0.000	0.186	0.474
Average daily gains (kg)	1.30a	1.18a	1.22a	1.03b	0.325	0.000	0.017	0.741
Hot carcass weight (kg)	275c	339b	395a	405a	11.9	0.000	0.099	0.349
Dressing percentage (%)	54.3c	54.1c	57.9b	61.5a	0.46	0.000	0.011	0.479
Conformation score[b]	3.5b	3.7b	4.7a	5.0a	0.09	0.000	0.587	0.483
Fatness score[c]	4.6a	4.1b	3.9b	4.1b	0.13	0.003	0.002	0.576
Subcutaneous fat layer[d] (mm)	14a	12a	12a	13a	0.9	0.330	0.078	0.379
First category cuts[e](% of carcass weight)	6.76c	7.08bc	7.13b	7.62a	0.091	0.000	0.008	0.681

[a] Least square means within the same row lacking a common letter are significantly different (Tukey, $P<0.05$).
[b] Conformation score: C=5, H=4, T=3, A=2, X=1 (Swiss classification grid widely equivalent to EUROP grading with C=E).
[c] Fatness score: 1 (low) to 5 (high fatness) equivalent to EUROP grading.
[d] Measured between the 12th and the 13th rib.
[e] Sum of the trimmed striploin, tenderloin and rump.

differ significantly in the thickness of the subcutaneous fat layer and fatness score (except Angus). There were also effects of fattening series in some growth and carcass traits, but these did not significantly interact with the breed group effects.

As intended, the IMF content was almost identical for all breeds (Table 2) with an average of 3.25%, and also the coefficients of variation in IMF content were comparable, accounting for 27, 21, 25 and 21% in the Angus, Simmental, Charolais and Limousin groups, respectively. Similarly, none of the marbling traits measured showed significant differences between breed groups. However, there was a trend ($P=0.1$) for the LD of the Angus steers to accumulate the highest proportion of visible fat within the three largest particles. There were significant positional effects on visible fat proportion of total muscle area (Fig. 1) which varied from 5.1% on average at the dorsal-lateral position to 9.3% at the dorsal-medial position. Steers of the two fattening series differed in IMF content and some marbling traits, but a significant interaction with breed group was only found for average particle size which remained unaffected by breed group and fattening series alone.

There was no significant difference between breed groups in pH and temperature of the LD measured 1 h p.m. (Table 3). The temperature decline from 1 to 3 h p.m. was significantly slower for the Limousin, the group with the heaviest carcasses and the most pronounced conformation. This was accompanied by a lower $pH_{3\ h}$ compared with all other breed groups (significant against Angus). Breed group differences in ultimate pH (48 h p.m.) were small but significant between Limousin and Simmental. Drip loss increased in the order of Angus, Simmental, Charolais and Limousin, while the opposite trend was apparent for cooking loss. When comparing Limousin and Angus, this resulted, on average in differences of 2.0 and 6.5 percentage units in drip loss and cooking loss, respectively. The LD of the Angus and the Charolais steers was significantly paler (higher L^*) than that of the Simmental steers, with the Limousin taking an intermediate position. This is in line with the correspondingly lower haem iron content of the

Table 2
Intramuscular fat content and video image analysed marbling traits of *M. longissimus dorsi* (LD) obtained from steers of different breeds

Variables	Angus	Simmental	Charolais	Limousin	SEM	*P*-values		
						Breed	Series	Breed×Series
Intramuscular fat (%)	3.23	3.25	3.25	3.27	0.178	0.999	0.001	0.972
Visible fat (% of LD)	8.0	7.1	7.1	7.2	0.47	0.437	0.051	0.192
CV[a] of visible fat (%)	34.4	32.0	29.5	28.9	2.74	0.483	0.484	0.153
Average fat particle size (mm^2)	1.7	1.5	1.7	1.5	0.10	0.216	0.864	0.019
Fat particle density (n/cm^2)	4.6	4.8	4.4	5.0	0.27	0.528	0.039	0.548
Three largest fat particles (% of visible fat)	31.2	27.2	22.9	25.9	2.32	0.100	0.006	0.064
Number of fat particles > 30 mm^2	2.6	2.4	2.8	3.7	0.42	0.176	0.776	0.576

[a] Coefficient of variation between quarters of the LD cut.

LD in Angus and Charolais relative to Simmental. Accordingly, there was a significant and negative correlation between haem iron content and lightness ($r=-0.68$, $P<0.001$). Breed groups did not differ significantly in redness and yellowness of the LD.

WBSF was not significantly different between breed groups (Table 3). However, significant positional differences within LD were found (Fig. 1), with lower shear force in the medial positions (28 N on average for the dorsal and ventral position) compared with the lateral positions (34 N). The average sarcomere length was significantly greater in the Angus meat, which also had the smallest number of sarcomeres equal to or shorter than 1.6 μm (significant against Limousin). The proportion of sarcomeres exceeding 2.3 μm and the variation in sarcomere length did not differ significantly. The MFI was initially (2 days p.m.) lowest in the Simmental steers compared with all other groups, but differences were no longer significant after ageing for a further 12 days. Shear forces, although not significantly different between groups, followed an inverse trend to the MFI at 2 days p.m., i.e. the highest shear forces corresponded to the lowest MFI values. Content and solubility of collagen were significantly higher in the Angus compared with the Limousin steers, with the Simmental and Charolais groups taking intermediate positions. Only a few meat quality traits were affected by fattening series and only in $pH_{48\ h}$ and $MFI_{48\ h}$ significant breed group×series interactions seen.

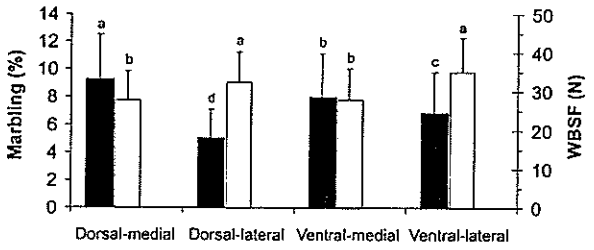

Fig. 1. Area of visible fat as a proportion of total muscle area (■) and Warner-Bratzler shear force (WBSF, □) measured at different positions within the LD (average of all breed groups). Means for variables from different positions lacking a common letter are significantly different (Tukey, $P<0.05$).

The meat of the Angus and the Limousin steers was judged significantly more tender than that of the Simmental steers (Table 4); the Charolais meat was scored intermediate. Correlations between panel tenderness and various other traits are listed in Table 5. The correlations calculated within breeds differed to some extent. However, in those variables, which were significant in the complete dataset, correlations within breeds were also oriented in the same direction. In detail, negative correlations of tenderness scores with WBSF (except Angus) and positive correlations with MFI, irrespective of the time p.m., were found. Although $pH_{3\ h}$ measurements ranged from 5.56 to 6.47 and temperature at 3 h p.m. from 27.4 to 36.6 °C no

Table 3
Meat quality traits measured in the *M. longissimus dorsi* of steers of different breeds slaughtered at a similar intramuscular fat content[a]

Variables	Angus	Simmental	Charolais	Limousin	SEM	*P*-values		
						Breed	Series	Breed×series
$pH_{1\ h}$[b]	6.59a	6.61a	6.59a	6.56a	0.031	0.691	0.019	0.947
$pH_{3\ h}$	6.22a	6.07ab	6.13ab	6.02b	0.040	0.006	0.740	0.571
$pH_{48\ h}$	5.54ab	5.57a	5.51ab	5.50b	0.018	0.047	0.154	0.033
$Temperature_{1\ h}$ (°C)	38.5a	37.9a	37.9a	38.9a	0.31	0.094	0.575	0.311
$Temperature_{3\ h}$ (°C)	31.4b	31.3b	32.3b	34.4a	0.40	0.000	0.005	0.536
$Drip\ loss_{48\ h}$ (%)	2.5c	3.0bc	3.6b	4.5a	0.21	0.000	0.323	0.052
$Cooking\ loss_{14d}$ (%)	20.6a	17.1b	15.8bc	14.1c	0.71	0.000	0.001	0.476
$Lightness_{14\ days}$ (L^*)	40.0a	37.3b	39.5a	38.1ab	0.54	0.001	0.888	0.224
$Redness_{14\ days}$ (a^*)	14.2a	14.3a	14.2a	14.7a	0.25	0.327	0.992	0.358
$Yellowness_{14\ days}$ (b^*)	4.3a	4.1a	4.7a	4.9a	0.30	0.250	0.246	0.113
$Heme\ iron_{48\ h}$ (mg/kg)	1.17b	1.40a	1.21b	1.27ab	0.050	0.011	0.235	0.080
$Warner\text{-}Bratzler\ shear\ force_{14\ days}$ (N)	29a	33a	32a	29a	1.4	0.181	0.122	0.267
$Sarcomere\ length_{48\ h}$ (μm)	1.85a	1.78b	1.77b	1.76b	0.019	0.005	0.851	0.954
CV of sarcomere length (%)[c]	6.7a	7.7a	8.5a	8.8a	0.57	0.060	0.725	0.913
Proportion of sarcomere ≤1.6 μm (%)	2.0b	6.0ab	9.1ab	12.2a	1.88	0.002	0.989	0.393
Proportion of sarcomere >2.3 μm (%)	1.8a	0.8a	1.5a	2.8a	1.07	0.597	0.745	0.680
$Myofibrillar\ fragmentation\ index_{48\ h}$	110a	88b	107a	111a	4.1	0.001	0.016	0.023
$Myofibrillar\ fragmentation\ index_{14\ days}$	143a	131a	125a	129a	5.2	0.098	0.486	0.073
$Collagen_{48\ h}$ (mg/100 g)	549a	536ab	525ab	482b	15.5	0.020	0.060	0.713
$Collagen\ solubility_{48\ h}$ (%)	34.3a	31.6ab	29.6ab	28.6b	1.36	0.024	0.000	0.332

[a] Least square means within the same row lacking a common letter are significantly different (Tukey, $P<0.05$).
[b] Indices represent the length of the period post-mortem.
[c] Coefficient of variation ($n=120$).

Table 4
Results of the sensory evaluation of the 14 day aged *M. longissimus dorsi* obtained from steers of different breeds slaughtered at similar intramuscular fat contents[a,b]

Variables	Angus	Simmental	Charolais	Limousin	SEM	*P*-values		
						Breed	Series	Breed×series
Tenderness	4.80a	3.98b	4.59ab	4.77a	0.178	0.008	0.053	0.472
Flavour intensity	4.45a	4.11a	4.35a	4.43a	0.129	0.237	0.959	0.706
Juiciness	3.62c	3.85bc	4.55ab	4.68a	0.208	0.001	0.344	0.850
Preference	4.61a	4.36a	4.84a	4.95a	0.157	0.056	0.035	0.744

[a] Least square means within the same row lacking a common letter are significantly different (Tukey, $P<0.05$).
[b] Sensory attributes were scored using the following scales for tenderness, flavour intensity, juiciness and preference: 1 = very tough, slight, dry and much disliked; 8 = very tender, strong, juicy and much liked.

Table 5
Correlations between selected traits and panel tenderness scores in steers of different breeds slaughtered at similar intramuscular fat contents

Observations	Panel tenderness score				
	Angus 16	Simmental 16	Charolais 16	Limousin 16	All data 64
Age (days)	0.07	0.01	0.24	−0.11	0.03
Hot carcass weight (kg)	0.28	−0.32	0.28	−0.23	0.05
Fat thickness 12/13th rib (mm)	−0.57*	−0.22	0.01	0.45	0.04
$pH_{3\ h}$	−0.39	−0.38	0.26	−0.42	−0.11
$Temperature_{3\ h}$ (°C)	0.05	0.03	−0.21	−0.25	0.04
$Cooking\ loss_{14\ days}$ (%)	0.10	−0.23	−0.05	−0.13	−0.06
$WBSF^{a}_{14\ days}$ (N)	0.28	−0.53*	−0.53*	−0.27	−0.43***
$Sarcomere\ length_{48\ h}$ (μm)	−0.22	0.09	0.16	0.29	0.15
$MFI^{b}_{48\ h}$	0.26	0.34	0.31	0.19	0.42***
$MFI_{14\ days}$	0.59*	0.61*	0.40	0.05	0.40***
$Collagen_{48\ h}$ (mg/100 g)	−0.03	0.27	−0.57*	−0.09	−0.16
$Collagen\ solubility_{48\ h}$ (%)	−0.32	0.31	−0.57*	−0.15	−0.19

[a] Warner-Bratzler shear force.
[b] Myofibrillar fragmentation index.
* $P<0.05$.
*** $P<0.001$.

significant linear or curvilinear relationship was found among these variables and both WBSF and tenderness scores within or over all breed groups. Significant correlations between collagen-related traits and tenderness were only observed within the Charolais group. It should be noted that the variation of slaughter age was larger in this group being 20.2% compared with the Limousin, Simmental and Angus which had coefficients of variation of 10.4, 10.2 and 5.3%, respectively. Breed groups did not significantly differ in flavour scores, but differences between breed groups were found in juiciness, with the meat of the Limousin and, to a lower extent, that of the Charolais steers being juicier than that of the Simmental and particularly the Angus steers. Juiciness scores were negatively correlated with cooking losses ($r=-0.75$, $P<0.001$). There was a trend for preference ($P<0.06$) in the order of Limousin, Charolais, Angus and Simmental. In the sensory evaluation no breed×series interactions were seen.

4. Discussion

In the present study, steers of four common beef breeds, varying greatly in development of maturity, were fattened under identical conditions until a similar IMF content was reached. This procedure resulted in major differences between breed groups in age at slaughter and carcass size. The daily gains expressed as an average of the whole fattening period were higher for animals reaching the target IMF content at lower age which explains why there were none of the typical breed differences in growth rate. Together with other genetic differences between breeds, this was likely to result in major differences in meat quality and, possibly, in the distribution of visible IMF in the LD, both of which may be important in the purchasing decision of the consumers. The chosen level of IMF of approximately 3.25% corresponds to 'slight degree of marbling', a grade, which was found to be preferred in a

study on visual quality and degree of marbling, involving US consumers (Killinger, Calkins, Umberger, Feuz, & Eskridge, 2000). In beef, 47% Swiss consumers preferred IMF contents of 3–4%, whereas 27% selected beef with no visible marbling (Chambaz et al., 2001). However, in Europe, carcasses similar to those investigated need specialized marketing since the commonly used grading would classify them, almost without exception as excessively fat and therefore of low value. As seen by the similarly thick subcutaneous fat layer, this restriction cannot be overcome by the use of a certain breed.

4.1. Marbling properties

A high degree of marbling is often associated with a good meat quality and can play an important role in purchasing decision and price. The actual sensory impression during consumption of the meat, however, seems to be independent of the marbling score. This was reported from surveys on meat quality, carried out in the USA (Brooks et al., 2000; Morgan et al., 1991). Nevertheless, marbling is still an important component of the US quality grading system and is also considered in the regulations of some US branded beef programs. These programs not only demand a minimum extent but also a fine distribution of marbling (AAA, 2001). However, none of the breed groups investigated in the present study were clearly superior in the traits describing marbling characteristics. Nevertheless, within the LD there were positional differences in both visible fat proportion and shear force, which appeared to be inversely related (Fig. 1). The latter might reflect a partial substitution of proteinous structures by fat, however as the relation was not really linear, this may be an artefact.

Since the four breed groups were equal in subcutaneous fat layer, IMF and marbling of the LD, it was possible to compare the sensory, chemical and physical meat quality traits of the different breed groups almost independently of the fat-related properties of the meat.

4.2. Meat colour

Meat colour is a further important determinant of the visual appearance of meat. Carpenter, Cornforth, and Whittier (2001) showed that consumer preferences for beef colour influenced the likelihood of purchase but—similarly to marbling—colour did not correspond with differences in eating satisfaction. As expected, in the present study lightness was inversely correlated to haem iron content. Haem iron content of muscle increases with age especially up to 24 months of age and then remains relatively stable (Renerre, 1982). This might explain the low haem iron content of the younger Angus but not the differences between the other groups. Thus, the high haem iron content of Simmental beef may be attributed to a genuine breed characteristic, either resulting from a more rapid increase in, or a generally higher content of total iron in the muscle.

4.3. Meat texture

Tenderness is one of the more important criteria for beef quality and it has been shown that consumers are ready to pay a higher price once assurred that the beef is tender (Dransfield, 1998). The sensory scoring revealed that Angus and Limousin beef was most tender, followed by Charolais and Simmental beef. Although not significantly different between breed groups, the WBSF followed the same trend and was significantly, however not closely, correlated with sensory tenderness for all animals. Since meat was obtained from steers and was aged for 14 days, the tenderness level was generally high and the variation in tenderness was relatively low. This probably contributed to the rather poor relationship between tenderness score and WBSF. The differences in tenderness between breed groups were generally in agreement with other studies, which however were not carried out at similar IMF content: Simmental beef was found to be less tender than that of their crosses with Angus (Dufey, 1988). Also crossbreeding with Red Holstein (Dufey, 1987) and Charolais (Branscheid & Herzog, 1996) improved the tenderness of Simmental beef. When comparing animals of the same age, Angus crosses with Charolais were found to yield the same tenderness as purebred Angus while crosses with Simmental and Limousin gave less tender meat (Koch et al., 1976). In contrast, no differences in tenderness were found between Simmental and Angus crossbred steers when slaughtered at equal backfat thicknesses (Laborde, Mandell, Tosh, Wilton, & Buchanan-Smith, 2001).

Several factors may be responsible for the breed group differences in tenderness found. Early post-mortem pH has been suggested as a factor affecting meat tenderness as it influences the activity of endogenous enzymes (O'Halloran, Troy, & Buckley, 1997). From several investigations (French et al., 2000; Marsh, Ringkob, Russell, & Swart, 1987; Pike, Ringkob, Beekman, Koh, & Gerthoffer, 1993) it appears that the glycolytic rate to give a $pH_{3\ h}$ of 6.0–6.1 results in the most tender meat. This can be either achieved by electrical stimulation (Marsh et al., 1987) or by producing heavy carcasses with a correspondingly slow temperature decline during chilling (Pike et al., 1993) as was the case with the Limousin group in the present study. However, ageing of the meat for 14 days decreased initial tenderness differences (French et al., 2000; O'Halloran et al., 1997) in agreement with the development of MFI in the present investigation. Accordingly no significant

relationship between $pH_{3\ h}$ and sensory tenderness of meat aged for 14 days was found in our and also other studies (Shackelford, Koohmaraie & Savell, 1994). Both Limousin and Simmental beef showed an ideal $pH_{3\ h}$, but Simmental beef was graded significantly lower in tenderness.

Another important factor in the myofibrillar component of tenderness may be sarcomere length, particularly when the $pH_{3\ h}$ is greater than 6.3 (Smulders, Marsh, Swartz, Russell, & Hoenecke, 1990), although a clear relationship between sarcomere length and tenderness is not always found (O'Halloran et al., 1997). One precondition for a good correlation seems to be the occurrence of cold or heat shortening (Shorthose & Harris, 1991). Some contraction obviously occurred in Limousin and, to a smaller extent, in Charolais and Simmental probably not due to cold but heat shortening. Lochner, Kauffman, and Marsh (1980) have shown that carcass size and fatness have an influence on cooling rate and can be at least as important in determining muscle cooling rate as the temperature and air velocity. Moreover it is unlikely that cold shortening occurred in Limousin because they had the lowest pH and the highest muscle temperature at 3 h p.m. and so should have a low risk of cold shortened. Lee and Ashmore (1985) observed contracted sarcomeres lengths (mean 1.66 μm) and increased toughness due to heat shortening in carcasses with similar backfat thickness and temperature at 3 h p.m. as in the Limousin group of our study although the carcasses in our study were about 100 kg heavier. In cold-shortened meat both contracted and stretched sarcomeres are present resulting in a great variation in sarcomere length (Locker, Davey, Nottingham, Haughey, & Law, 1975). This was not the case in this study, and it is assumed that the 14 day-ageing period was sufficient to offset or overcome the effect of shortening, as Limousin tenderness scores were similar to those of the Angus which had almost no sarcomeres contracted to less than 1.6 μm. Accordingly, the poor relationship between sarcomere length and tenderness scores and shear force is unclear.

In the present study, MFI was a suitable indicator of tenderness, as observed in other studies (Culler et al., 1978; Vestergaard, Therkildsen, Henckel, Jensen, Andersen, & Sejrsen, 2000), however, it does not explain breed group differences in the tenderness of the aged LD. MFI particularly reflects changes occurring during ageing of meat. In the present experiment, MFI was measured at 48 h and at 14 days p.m. In this period MFI increased by 30, 49, 17 and 16% in the Angus, Simmental, Charolais and Limousin groups, respectively, thus decreasing the initial variation among breeds (particularly Simmental vs. others). Therefore it can be assumed that, with reduced ageing, Simmental beef would have been even more inferior in tenderness compared with the other groups.

The connective tissue-related traits were as expected, with steers from breeds slaughtered at higher ages expressing lower collagen solubility reflecting the increasing formation of mature or heat-stable crosslinks (Purslow, 1994). In the Limousin group, this was compensated for by a lower collagen content due to dilution of connective tissue by other muscle tissues. The only significant correlations between collagen-related traits and panel tenderness were found in the Charolais group, which also showed the greatest variation in age. Nevertheless the negative relationship between collagen solubility and tenderness in the Charolais was not expected.

4.4. Flavour, juiciness and water-holding capacity of the meat

Some studies have reported no real differences in meat flavour between breeds (Koch et al., 1976, 1979, 1982; Wheeler et al., 1996; Wheeler, Cundiff, Shackelford, & Koohmaraie, 2001) but Laborde et al. (2001) noted higher flavour scores in Simmental crossbred steers than in Angus steers slaughtered at similar backfat thicknesses, but the Simmental crossbreds were 73 days older and had a 31% higher IMF content. Since in the present study clear breed group differences in slaughter age also occurred and intensity of flavour is known to develop with increasing animal age (Lawrie, 1991), differences in flavour were expected but not found.

The present study revealed clear breed group differences in cooking loss and juiciness of the meat, traits which were closely and inversely correlated. It seems that differences in age at slaughter, which represent indirect effects of breed through the breed-specific rate of IMF accretion are related to juiciness. Breed group differences in juiciness were far more pronounced than in other studies comparing beef not at the same IMF contents but at the same age or weight (e.g. Crouse, Cross, & Seideman, 1985). The age-dependence, as a result of the decline in muscle water content with age, has been shown to be closely associated with cooking loss in Simmental cattle (Lüdden, 1991). Nevertheless in the present study the meat had a similar chemical composition and therefore the apparent relationship between age and juiciness remains unclear. Another factor determining breed group differences in cooking loss could have been the differences in size of the LD slices (small in Angus). However, no direct relationship between surface, weight and surface to weight ratio of the LD slice and the level of cooking loss was found. Ranking in drip loss was opposite to that in cooking loss and juiciness. Drip loss involves other compartments of bound water than cooking loss and therefore does not correlate with cooking loss (Honikel, 1986). In the present study, overall group differences in cooking loss were far greater than those in drip loss.

4.5. Overall sensory preference of meat

Panellists tended ($P<0.06$) to prefer the LD of Limousin and Charolais steers. This can be explained by the lower juiciness of the Angus beef and, additionally, the lower tenderness of the Simmental beef. Generally, the results of other studies, although not carried out under the precondition of a similar IMF content, indicate that differences in meat palatability are small between Bos taurus breed groups (Koch et al., 1979; Monin & Ouali, 1991) and not very consistent due to the large inherent variability compared to that between breeds (Wheeler et al., 1996).

5. Conclusions

The present study illustrated that beef from different breeds, when reared under the same conditions and compared at the same IMF content, may differ substantially in quality. This was significant even with a sample size of only 16 animals per breed group. These differences might be less pronounced when age differences at slaughter are reduced by a variation of the feeding intensity. However, semi-intensive feeding systems could be attractive by reducing feeding costs, particularly in grassland regions. Under these conditions, Charolais and Limousin could have an advantage, expressed in favourable juiciness and tenderness, low cooking losses and other economically important carcass traits. On the other hand, these breeds will provide very heavy carcasses and an unusually long fattening period is required when an IMF content of more than 3% is demanded. For these reasons intensive fattening systems would be advisable. Angus beef, also very tender but with higher cooking loss, would have the advantage of a much shorter fattening period and provides the best choice for extensive systems. Simmental beef was ranked inferior; therefore, crossbreeding might improve the Simmental offspring's beef quality.

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