Arch. Tierz., Dummerstorf 44 (2001) 5, 473-488

Swiss Federal Research Station for Animal Production[1], Posieux, Switzerland, and Institute of Animal Sciences, Group of Animal Nutrition[2], Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

ALAIN CHAMBAZ[1], MICHAEL KREUZER[2], MARTIN R. L. SCHEEDER[2] and PIERRE-ALAIN DUFEY[1]

Characteristics of steers of six beef breeds fattened from eight months of age and slaughtered at a target level of intramuscular fat

II. Meat quality

Summary

Meat quality of Angus (AN), Simmental (SI), Charolais (CH), Limousin (LI), Blonde d'Aquitaine (BL), and Piedmontese (PI) steers (n=22 per breed group) was measured in the M. *longissimus dorsi* (M.l.d.) and the M. *biceps femoris, regio glutea* (M.b.f.). Animals were fattened in two subsequent series on a forage-based diet until a target level of 3.5% intramuscular fat (IMF) was reached according to real-time ultrasound assessments in the live animals or until 15 months of fattening had passed. Series 1 was performed in a tie-stall barn while a loose-housing system with straw bedding was applied in series 2. The actually measured IMF contents in M.l.d. were 3.35, 3.47, 3.49, 3.48, 2.34 and 2.40 % for AN, SI, CH, LI, BL and PI, respectively. Breed group differences in IMF content were mostly accompanied by a contrary variation either in muscle water or protein content. Muscle cholesterol levels were similar for all breeds amounting to 47 and 51 mg/100 g on average in M.l.d. and M.b.f., respectively. Early and late postmortem muscle pH was relatively similar among breeds, but water-holding capacity, measured as losses due to drip, ageing, thawing and cooking, was unfavourably high in AN (drip loss excepted) in both muscles. Cooking loss tended to be lowest in PI, drip loss in SI. The AN showed the palest meat. In line with lightness, heme iron contents were clearly lowest in both muscles in the AN steers. There was no relationship found between IMF and shear force among breed groups. No significant differences between breed groups occurred in M.l.d. collagen solubility and shear force. Apart from breed differences, there were several differences noted between fattening series, namely clearly better water-holding capacity and lower shear force of the meat from series 2 (group housing) than from series 1 (tied system). The results indicate that in steers of similar IMF content and raised under the same feeding and management conditions, differences in most M.l.d. and M.b.f. quality traits were apparent, with the exception of shear force and M.l.d. collagen solubility.

Key Words: beef, steers, breed, meat quality, intramuscular fat, cholesterol

Zusammenfassung

Titel der Arbeit: **Mast von Ochsen sechs verschiedener Fleischrinderrassen ab einem Alter von acht Monaten bis zum Erreichen eines Zielwerts im intramuskulären Fettgehalt. 2. Mitt.: Fleischqualität**

An Ochsen der Rassen Angus (AN), Simmental (SI), Charolais (CH), Limousin (LI), Blonde d'Aquitaine (BL), and Piemonteser (PI) (n=22 je Rassengruppe) wurde die Fleischqualität im M. *longissimus dorsi* (M.l.d.) und im M. *biceps femoris, regio glutea* (M.b.f.) gemessen. Die Tiere wurden in zwei aufeinanderfolgenden Durchgängen mit einer grundfutterbetonten Ration gemästet und zwar bis zu einem Zielwert von 3,5 % intramuskulärem Fett (IMF; geschätzt mittels Echtzeit-Ultraschallmessung) oder bis 15 Monate Mast vergangen waren. Durchgang 1 erfolgte in einem Anbindestall, Durchgang 2 im Laufstall mit eingestreuten Liegeboxen. Die tatsächlich gemessenen IMF-Gehalte im M.l.d. lagen bei 3,35, 3,47, 3,49, 3,48, 2,34 und 2,40 % für AN, SI, CH, LI, BL und PI. Die Unterschiede zwischen den Rassengruppen im IMF-Gehalt waren zumeist durch gegensätzliche Verschiebungen im Wasser- oder im Eiweißgehalt des Muskels gekennzeichnet. Die Cholesterolgehalte von M.l.d. und M.b.f. lagen im Mittel bei 47 und 51 mg/100 g und waren für alle Rassen gleich. Der früh- und spätpostmortal erhobene pH-Wert fiel in allen Rassengruppen ziemlich ähnlich aus, dennoch war das Wasserbindungsvermögen, welches über den Drip-, Reifungs, Auftau- und Kochverlust gemessen wurde, bei den AN (außer im Dripverlust) in beiden Muskeln ungünstig. Die PI-Muskeln hatten tendenziell den niedrigsten Kochverlust, der Dripverlust war bei den SI am niedrigsten. Die AN-Muskeln waren am hellsten. Entsprechend waren bei den AN-Ochsen die Hämeisengehalte beider Muskeln am niedrigsten. Zwischen den Rassengruppen

wurde keine Beziehung zwischen dem IMF-Gehalt und der Scherkraft gefunden. Im Vergleich der Gruppen ergaben sich keine signifikanten Unterschiede in der Kollagenlöslichkeit und der Scherkraft des M.l.d. Neben den Rassenunterschieden wurden auch einige Unterschiede zwischen den beiden Mastdurchgängen gefunden, insbesondere ein klar besseres Wasserbindungsvermögen und eine geringere Scherkraft des Fleisches in Durchgang 2 (Laufstall) gegenüber Durchgang 1 (Anbindestall). Die Ergebnisse belegen, dass sich bei der Ochsenmast auf denselben IMF-Gehalt und der Einhaltung gleicher Fütterungs- und Haltungsbedingungen, Unterschiede in den meisten Qualitätsmerkmalen des M.l.d. und M.b.f., außer der Scherkraft und der Kollagenlöslichkeit (M.l.d.), ergeben.

Schlüsselwörter: Rindfleisch, Ochsen, Rasse, Fleischqualität, intramuskuläres Fett, Cholesterol

1. Introduction

Interest in label beef production is consistently increasing in Europe (NEUMANN and MARTIN, 1991; GERHARDY, 1994; ROCHE et al., 2000) in a situation of declining consumption of red meat and a general decrease in acceptance of conventionally produced and marketed beef. Labels intend to provide a quality which is or can be especially oriented towards consumer demands including controlled beef quality and a greater consideration of the welfare of the animals (BOISSY et al., 2000). Although pricing systems still heavily rely on carcass rather than on actual meat quality traits, labels are expected to guarantee a certain level and, particularly, homogeneity of beef quality (BRANSCHEID and CLAUS, 1989) in order to fulfil the consumer's implicit expectations (TEMISAN, 1990). Current Swiss beef labels encourage both the use of purebred beef breed cattle in order to profit from a higher carcass quality and, as category, steers to improve meat quality. This should provide products which can be distinguished from conventional continental European beef which is based on calves largely representing a by-product of dairy husbandry. Visual perception of the products is often associated with beef quality and can affect purchase decision of the consumers. One main component of visual quality, together with colour, is marbling which expresses proportion and distribution of intramuscular fat (IMF) in the M. *longissimus dorsi* (M.l.d.). It is still unclear in how far known breed differences in meat quality traits such as water-holding capacity and tenderness (DUFEY, 1987, 1988a; TATUM et al., 1990; WHEELER et al., 1996) can be recovered under the condition of a similar extent of marbling. Furthermore, the repeatedly postulated low cholesterol content of Piedmontese beef (MONTANA RANGE, 2001) might get lost if really existing when the cattle is fed to high IMF contents. The objective of the present investigation was to compare the meat quality of six beef breeds fattened under the same conditions. The animals of this study were slaughtered at a target level of 3.5 % IMF. This level is higher than usually found in Switzerland (DUFEY and CHAMBAZ, 1999). As reported in a first communication (CHAMBAZ et al., 2001), clear differences in growth and carcass quality developed between the breeds. Two breeds were unable to reach the target value in IMF, but were kept in the comparison in order to give information of their meat characteristics under the conditions applied.

2. Materials and methods

A total of 132 steers of six beef breeds, namely Angus (AN), Simmental (SI), Charolais (CH), Limousin (LI), Blonde d'Aquitaine (BL), and Piedmontese (PI), selected at 8 months of age from suckler beef rearing systems, were fattened in two subsequent series (11 animals/breed/series). The first series was carried out in a tie-stall barn and series 2 in a loose housing system with straw bedding. The animals had

ad libitum access to a diet consisting of maize silage, 520 g, grass silage, 260 g, and concentrate, 220 g per kg of dry matter. Steers either were slaughtered when the ultrasonically assessed IMF reached 3.5 % in the *Musculus longissimus dorsi* (M.l.d.) between the 12th and 13th rib or after a maximum of 15 months of fattening (CHAMBAZ et al., 2001). This approach resulted in large differences in slaughter age. Members of the AN, SI, CH, LI, PI and BL groups finished the experiment at an average age of 381, 509, 529, 610, 683 and 690 days, respectively. The coefficient of variation in slaughter age was lowest for AN with 6.6 % and highest for CH with 19.6 %. Further details on the experimental procedure are given in CHAMBAZ et al. (2001).

The animals were slaughtered in a commercial slaughter plant after approximately 1 h of transport by bleeding after captive-bolt stunning. Measurements of pH were performed 1 h and 48 h post mortem (p.m.) in the M.l.d. at the 10th rib and in the *Musculus biceps femoris, regio glutea* (M.b.f.) with a portable pH meter (WTW 197S, Wissenschaftlich-Technische Werkstätten GmbH, D-Weilheim) equipped with a Sensor EB4 probe (Wintion, CH-Gerzensee). Samples of the M.l.d. and M.b.f. were taken from the left carcass side 48 h p.m. Meat colour was determined with a Chroma-Meter (CR-300, Minolta, CH-Dietikon-Zürich) applying the light source D65, which yielded data for L* (lightness; 0-100 = dark-light), a* (red-green index) and b* (yellow-blue index) when directly put onto fresh cuts of M.l.d. and M.b.f. 48 h and 14 d p.m. These samples were sealed under vacuum as slices of 2 cm thickness. Separate samples of approximately 300 g were frozen at –30 °C until analysed for chemical composition, heme iron and cholesterol content. Two slices, also vacuum-packed, were stored for 12 days at +2 °C for measurements in the aged meat. Weight loss during this period was determined as ageing loss. Afterwards the samples were stored frozen (–30 °C) until being thawed at 2–4 °C over 24 h and then broiled for 5 min on a grill (type BP-50, Beergrill AG, CH-Zürich) at 195 ± 5 °C by direct radiant heat with the samples repeatedly turned during heating. The apparatus was connected to an external electronical thermoregulator (Ematherm A, Trafag AG, CH-Männedorf) and a thermoprobe (Pt 100, Moser AG, CH-Hombrechtikon) to control temperature. According to preliminary assessments, this procedure resulted in a meat core temperature of approximately 68 °C. Within these procedures, losses due to thawing and cooking (directly after cooking) were recorded. In independent samples, drip losses were quantified as described by HONIKEL (1998) storing fresh 2 cm thick slices of each muscle for 48 h at 2 °C. Cooked samples cooled to ambient temperature were sheared by the original Warner-Bratzler device (model 3000, G-R Electric MFG Co, Manhattan, Kansas, USA). Ten cores per sample of 1.27 cm diameter were obtained parallel to fibre orientation from the cooked slices according to KASTNER and HENRICKSON (1969) with an electrical drill at a speed providing uniform samples.

In the raw, homogenised muscle samples, heme iron contents were determined as pigments according to BARTON (1967) by extracting pigments with acetone and spectral photometric determination at a wavelength of 640 nm on a Lambda 2 photometer (Perkin-Elmer, D-Überlingen). Heme iron was calculated assuming the conventionally applied value of 9.06 % heme iron in pigment. Cholesterol was enzymatically determined by a colorimetric method (BOEHRINGER MANNHEIM, 1994) with the same spectrophotometer as described for heme iron analysis, but at a

wavelength of 405 nm. As described in the guidelines (BOEHRINGER MANNHEIM, 1994), homogenized muscle samples were hot saponified during 30 min in advance of the cholesterol determination. Lyophilized samples of M.l.d. and M.b.f. were analysed for their contents of dry matter (3 h, 105 °C) as well as ash (total ash; 4 h, 550 °C; NAUMANN and BASSLER, 1997), fat (petrol ether extract; SLB, 1969) and protein (crude protein; KJELDAHL method; AOAC, 1995). Furthermore the lyophilized samples were analyzed for collagen content (hydroxyproline × 8) as described by ARNETH and HAMM (1971) adapted to the Technicon (Plainfield, New Jersey, USA) analyse chain. Collagen hydrothermal solubility at 90 °C was determined as outlined by KOPP et al. (1977). All chemical analyses were carried out in two replicates.

Data were statistically analysed with the NCSS program (version 1997, Hintze, Kaysville, Utah, USA). In a first evaluation, data of both series were included in order to be able to compare overall series differences, using a two-way ANOVA with breed and series as fixed effects and breed × series interactions. Because interactions between breed and series frequently occurred in meat quality traits, data were finally analysed separately for each series by one-way ANOVA with breed as fixed effect in the model. The Tukey test was used for multiple comparison among means regarding $P < 0.05$ as significant.

3. Results

On average of both experimental series the actually measured IMF contents in M.l.d. (means ± SD) were 3.35 ± 1.12, 3.47 ± 0.93, 3.49 ± 1.11, 3.48 ± 1.08, 2.34 ± 0.64 and 2.40 ± 0.63 % for AN, SI, CH, LI, BL and PI, respectively (Table 1). The corresponding levels found in M.b.f. were 3.35 ± 0.98, 3.92 ± 0.94, 3.02 ± 1.14, 2.69 ± 0.93, 2.01 ± 0.75 and 1.71 ± 0.65 %. Therefore, at an overall slightly lower average IMF content of M.b.f. of 2.78 % compared to 3.09 % in M.l.d., the breed differences were roughly also reflected in M.b.f., particularly with again the lowest contents being found in BL and PI (partially significant against other breeds). Part of the within-breed variation in IMF content resulted from significant series differences as the average IMF content achieved was lower in series 1 than in series 2. The M.l.d and M.b.f. of BL and PI had the highest protein content of all groups on average of both series, particularly when compared with AN, SI and CH, whereas LI held an intermediate position. Breed group differences in IMF content were mostly associated by contrary variations in muscle water and protein content. In line with protein and dry matter content there was a small but partially significant variation in ash content of the two muscles. In contrast, no significant differences were observed between breed groups in cholesterol content of both muscles ranging at a similar level of around 47 and 51 mg/100 g in M.l.d. and M.b.f., respectively.

The differences in early postmortem muscle pH were small and mostly not significant among groups for both muscles (Table 2). Moreover none of the animals presented a pH_1-value below 6.2, indicating that no PSE (pale, soft, exsudative) meat was found. Ultimate muscle pH, measured at 48 h p.m., was in the desired range with an average of 5.54 (max: 5.82) in the M.l.d. and of 5.50 (max: 5.79) in the M.b.f., when pooled over both series (slightly but significantly higher in series 2). None of the animals expressed an ultimate muscle pH above 6.0, regarded as the threshold level for DFD

(dark, firm, dry) meat or DCB (dark cutting beef). In series 1, LI muscles had a significantly lower pH_{48} in the M.l.d. compared to PI, with the other groups remaining intermediate.

Table 1
Chemical composition of the M.l.d. and the M.b.f. (wet weight) of the steers originating from different beef breeds (n=11 per series) (Chemische Zusammensetzung des M.l.d. und des M.b.f. der Ochsen von verschiedenen Mastrassen; n=11 je Versuchsdurchgang)[1]

	AN	SI	CH	LI	BL	PI	Average	SEM
M. *longissimus dorsi*								
Water (g/100 g)								
Series 1	74.74^{ab}	74.03^{b}	74.55^{ab}	74.41^{ab}	75.29^{a}	75.17^{a}	74.70^{y}	0.273
Series 2	74.30^{a}	73.64^{ab}	73.69^{ab}	72.89^{b}	73.86^{ab}	74.14^{a}	73.75^{z}	0.294
Ash (g/100 g)								
Series 1	0.99	1.01	1.02	1.01	0.98	0.97	1.00^{z}	0.015
Series 2	0.99^{d}	1.03^{cd}	1.06^{bc}	1.06^{bc}	1.10^{b}	1.18^{a}	1.07^{y}	0.017
Protein (g/100 g)								
Series 1	21.29	21.47	21.26	21.68	21.55	21.49	21.46^{z}	0.218
Series 2	21.06^{d}	21.82^{bcd}	21.43^{cd}	22.24^{abc}	22.92^{a}	22.57^{ab}	22.01^{y}	0.219
Fat (g/100 g)								
Series 1	2.99^{ab}	3.50^{a}	3.30^{ab}	2.88^{ab}	2.25^{b}	2.49^{ab}	2.90^{z}	0.268
Series 2	3.70^{a}	3.43^{ab}	3.69^{a}	4.07^{a}	2.44^{b}	2.30^{b}	3.27^{y}	0.280
Cholesterol (mg/100 g)								
Series 1	47.5	47.5	48.4	48.8	48.7	48.0	48.1^{y}	0.98
Series 2	47.1	46.4	45.8	45.6	46.4	47.8	46.5^{z}	0.68
M. biceps femoris								
Water (g/100 g)								
Series 1	76.29^{a}	74.40^{c}	75.83^{ab}	75.31^{abc}	75.66^{ab}	74.98^{bc}	75.41^{y}	0.239
Series 2	74.78	75.02	75.33	74.61	74.98	75.21	74.99^{z}	0.245
Ash (g/100 g)								
Series 1	0.96^{d}	0.97^{cd}	0.99^{cd}	1.01^{bc}	1.04^{ab}	1.06^{a}	1.01^{z}	0.010
Series 2	0.98^{c}	1.11^{ab}	1.04^{bc}	1.18^{a}	1.06^{abc}	1.09^{abc}	1.08^{y}	0.032
Protein (g/100 g)								
Series 1	19.78^{c}	19.80^{c}	19.88^{c}	20.66^{b}	21.18^{ab}	21.60^{a}	20.49	0.163
Series 2	19.58^{c}	19.57^{c}	19.55^{c}	20.65^{b}	21.16^{ab}	21.70^{a}	20.37	0.154
Fat (g/100 g)								
Series 1	2.80^{b}	4.00^{a}	2.57^{bc}	2.28^{bc}	1.73^{c}	1.88^{bc}	2.54^{z}	0.254
Series 2	3.89^{a}	3.83^{a}	3.46^{a}	3.10^{ab}	2.29^{bc}	1.54^{c}	3.02^{y}	0.262
Cholesterol (mg/100 g)								
Series 1	52.0	51.9	50.2	51.1	50.6	49.7	50.9	1.46
Series 2	52.0	51.8	50.8	50.4	50.2	50.5	51.0	0.81

AN = Angus, SI = Simmental, CH = Charolais, LI = Limousin, BL = Blonde d'Aquitaine, PI = Piedmontese
[1]Means within one line without a common superscript differ significantly ($P<0.05$); series averages within the same variable with different superscripts are significantly different ($P<0.05$).

Table 3 describes traits of water-holding capacity of the meat. The LI showed the highest M.l.d. drip loss on average of both series. In M.b.f. the pattern was not the same, with the BL having the highest and AN and SI showing the lowest drip loss. Drip loss was higher in both muscles in series 2 especially in BL, whereas AN meat showed an inverse pattern. PI had the lowest ageing losses in both series for M.l.d. and M.b.f., whereas M.l.d. of BL and SI (only series 2) and M.b.f. of AN showed significantly higher ageing losses. On average of both series, the AN expressed the highest thawing and cooking losses for both muscles whereas the losses were lowest in BL and PI. This illustrates that, within the different losses measured for the same muscle, only thawing and cooking losses, making up the major proportion of total losses, expressed a similar pattern over breeds. Accordingly, the overall water-holding

Table 2
Development of pH of the M.l.d. and the M.b.f. of the steers originating from different beef breeds (n=11 per series) (Verlauf des pH-Wertes von M.l.d. und M.b.f. der Ochsen von verschiedenen Mastrassen; n=11 je Versuchsdurchgang)[1]

	AN	SI	CH	LI	BL	PI	Average	SEM
M. *longissimus dorsi*								
$pH_{1\,h}$								
Series 1	6.54	6.57	6.54	6.48	6.67	6.60	6.57	0.054
Series 2	6.61^{ab}	6.62^{ab}	6.65^{a}	6.63^{ab}	6.63^{ab}	6.51^{b}	6.61	0.034
$pH_{48\,h}$								
Series 1	5.55^{ab}	5.56^{ab}	5.49^{ab}	5.45^{b}	5.53^{ab}	5.58^{a}	5.53^{z}	0.027
Series 2	5.55^{ab}	5.56^{ab}	5.52^{b}	5.56^{ab}	5.58^{a}	5.59^{a}	5.56^{y}	0.014
M. *biceps femoris*								
$pH_{1\,h}$								
Series 1	6.49	6.53	6.56	6.51	6.58	6.57	6.55^{z}	0.078
Series 2	6.64	6.66	6.66	6.67	6.60	6.64	6.64^{y}	0.039
$pH_{48\,h}$								
Series 1	5.52	5.49	5.46	5.43	5.52	5.47	5.48^{z}	0.022
Series 2	5.49^{b}	5.52^{ab}	5.51^{ab}	5.52^{ab}	5.54^{a}	5.55^{a}	5.52^{y}	0.012

[1]Means within one line without a common superscript differ significantly (P<0.05); series averages within the same variable with different superscripts are significantly different (P<0.05).

Table 3
Water holding capacity of the M.l.d. and the M.b.f. of the steers originating from different beef breeds (n=11 per series) (Wasserbindungsvermögen des M.l.d. und des M.b.f. der Ochsen von verschiedenen Mastrassen; n=11 je Versuchsdurchgang)[1]

	AN	SI	CH	LI	BL	PI	Average	SEM
M. *longissimus dorsi*								
Drip loss (%)								
Series 1	3.09^{b}	2.57^{b}	3.54^{ab}	4.30^{a}	2.92^{b}	2.54^{b}	3.16	0.271
Series 2	1.76^{d}	3.23^{bc}	3.72^{abc}	4.26^{ab}	4.29^{a}	2.89^{c}	3.36	0.253
Ageing loss (%)								
Series 1	3.94	3.66	3.86	3.47	4.23	3.44	3.77^{y}	0.214
Series 2	3.40^{ab}	3.78^{a}	3.44^{ab}	3.08^{ab}	3.60^{a}	2.72^{b}	3.33^{z}	0.180
Thawing loss (%)								
Series 1	7.61^{a}	6.66^{ab}	5.97^{b}	5.77^{b}	5.36^{b}	5.18^{b}	6.09^{z}	0.379
Series 2	8.79^{a}	8.14^{ab}	7.52^{abc}	6.51^{bc}	6.30^{c}	6.72^{bc}	7.33^{y}	0.429
Cooking loss (%)								
Series 1	22.18^{a}	18.55^{ab}	17.00^{b}	15.37^{b}	15.12^{b}	15.58^{b}	17.30^{y}	0.903
Series 2	17.30^{a}	14.82^{ab}	14.76^{ab}	12.99^{b}	11.70^{b}	12.03^{b}	13.93^{z}	0.824
M. *biceps femoris*								
Drip loss (%)								
Series 1	2.24^{ab}	1.44^{b}	2.56^{a}	2.62^{a}	2.77^{a}	2.72^{a}	2.39	0.201
Series 2	1.83^{c}	1.93^{c}	2.75^{b}	2.91^{ab}	3.45^{a}	2.71^{b}	2.59	0.156
Ageing loss (%)								
Series 1	3.17^{a}	2.58^{ab}	3.08^{ab}	2.63^{ab}	2.96^{ab}	2.39^{b}	2.80	0.180
Series 2	3.16^{a}	2.70^{ab}	2.61^{ab}	2.92^{ab}	2.85^{ab}	2.54^{b}	2.80	0.138
Thawing loss (%)								
Series 1	7.05^{a}	5.65^{ab}	6.33^{ab}	5.31^{ab}	5.15^{ab}	4.43^{b}	5.65	0.464
Series 2	7.71^{a}	5.81^{b}	6.51^{ab}	5.29^{b}	5.28^{b}	5.14^{b}	5.96	0.351
Cooking loss (%)								
Series 1	18.67^{a}	13.32^{b}	15.18^{ab}	12.53^{b}	12.37^{b}	11.55^{b}	13.94^{y}	0.896
Series 2	13.58^{a}	11.22^{ab}	13.32^{ab}	12.70^{ab}	10.68^{b}	10.72^{ab}	12.04^{z}	0.692

[1]Means within one line without a common superscript differ significantly (P<0.05); series averages within the same variable with different superscripts are significantly different (P<0.05).

capacity was low in AN and high in PI. Muscles of animals in series 2 expressed a lower cooking loss than those in series 1. Water-holding capacity of M.b.f. was on average better than that of M.l.d. in all types of losses measured.

Table 4
Colour after 14 d of ageing and heme iron content of the M.l.d. and the M.b.f. of the steers originating from different beef breeds (n=11 per series) (Farbe nach 14 Tagen Reifung und Hämeisengehalt des M.l.d. und des M.b.f. der Ochsen von verschiedenen Mastrassen; n=11 je Versuchsdurchgang)[1]

	AN	SI	CH	LI	BL	PI	Average	SEM
M. *longissimus dorsi*								
L*								
Series 1	39.8^{a}	36.9^{bc}	40.1^{a}	38.3^{ab}	36.2^{bc}	34.5^{c}	37.6	0.73
Series 2	40.2^{a}	37.7^{abc}	39.0^{ab}	37.4^{bc}	37.7^{abc}	36.3^{c}	38.0	0.60
a*								
Series 1	14.1	14.3	13.9	14.8	13.8	13.4	14.1	0.39
Series 2	14.3^{ab}	14.7^{a}	14.5^{a}	14.6^{a}	13.3^{b}	13.7^{ab}	14.2	0.25
b*								
Series 1	4.0^{ab}	4.1^{ab}	4.7^{ab}	5.2^{a}	3.8^{ab}	3.5^{b}	4.2	0.42
Series 2	4.5^{a}	4.3^{ab}	4.5^{a}	4.2^{ab}	3.6^{bc}	2.9^{c}	4.0	0.21
Heme iron (mg/100 g wet weight)								
Series 1	1.11^{b}	1.50^{a}	1.13^{b}	1.28^{ab}	1.46^{a}	1.59^{a}	1.35	0.075
Series 2	1.21^{b}	1.52^{ab}	1.31^{ab}	1.38^{ab}	1.36^{ab}	1.61^{a}	1.40	0.082
M. *biceps femoris*								
L*								
Series 1	38.3^{ab}	36.4^{b}	38.9^{a}	37.4^{ab}	36.9^{ab}	36.8^{ab}	37.5	0.58
Series 2	38.6^{a}	36.6^{b}	36.8^{ab}	36.2^{b}	37.1^{ab}	36.7^{ab}	37.0	0.48
a*								
Series 1	16.6	17.0	16.9	16.7	16.3	16.3	16.6^{z}	0.31
Series 2	17.0^{ab}	17.3^{a}	17.3^{a}	17.1^{ab}	16.7^{ab}	16.3^{b}	17.0^{y}	0.22
b*								
Series 1	4.7	5.4	6.2	5.7	5.0	5.0	5.3	0.42
Series 2	6.1^{a}	5.8^{ab}	5.8^{ab}	5.3^{ab}	5.0^{ab}	4.8^{b}	5.5	0.28
Heme iron (mg/100 g wet weight)								
Series 1	1.65^{b}	2.22^{a}	1.75^{b}	2.06^{ab}	1.94^{ab}	1.99^{ab}	1.94^{z}	0.101
Series 2	1.87^{b}	2.17^{ab}	2.12^{ab}	2.27^{a}	2.03^{ab}	2.01^{ab}	2.08^{y}	0.080

[1]Means within one line without a common superscript differ significantly ($P<0.05$); series averages within the same variable with different superscripts are significantly different ($P<0.05$).

Meat-colour related traits are given in Table 4. The M.l.d. and M.b.f. of the AN and CH steers were lighter than those of the other groups, and PI steers had the darkest M.l.d. and one of the darkest M.b.f. In both muscles, BL and PI showed a trend to less reddish and yellowish meat than that of the other breed groups. As expected, during ageing for 12 days colour turned towards higher lightness and redness in both muscles (data of non-aged meat not shown). The variation in M.l.d. lightness during ageing was significantly higher in AN than in SI with intermediate values in the other breed groups (data not shown). Heme iron content was lowest for AN and CH steers in both muscles and was highest for PI and SI in M.l.d. as well as for SI and LI in M.b.f. The M.b.f. heme iron content was higher by 44 % compared with that of the M.l.d. There was a significant negative correlation between heme iron content and L* in both muscles ($r = -0.77$ in M.l.d. and $r = -0.65$ in M.b.f., $P < 0.001$).

Shear forces were not significantly different in M.l.d. among groups, but AN M.l.d. tended to have low values (Table 5). There was a significant decrease in shear values in the second series and especially in SI and PI. Unlike as in the M.l.d., there were significant differences among groups in shear force of M.b.f., but the trend remained

similar. As expected, shear force and collagen contents were higher in the M.b.f. compared to M.l.d. although at similar collagen solubility. Muscle collagen content was higher in AN, SI and CH than in LI (only M.l.d.), BL and PI. There were no significant differences in M.l.d. collagen solubility among breed groups, but AN tended to have the highest solubility in both series, following the same trend as in shear force. Collagen solubility in M.l.d. increased in series 2 (+22 %) especially in the PI, LI and SI.

Table 5
Collagen properties and shear force of the M.l.d. and the M.b.f. of the steers originating from different beef breeds (n=11 per series) (Kollageneigenschaften und Scherkraft des M.l.d. und des M.b.f. der Ochsen von verschiedenen Mastrassen; n=11 je Versuchsdurchgang)[1]

	AN	SI	CH	LI	BL	PI	Average	SEM
M. longissimus dorsi								
Collagen (mg/100 g wet weight)								
Series 1	537^{a}	536^{a}	515^{ab}	470^{ab}	481^{ab}	438^{b}	496	19.7
Series 2	549^{a}	541^{a}	560^{a}	496^{ab}	426^{c}	476^{bc}	508	15.4
Collagen solubility (%)								
Series 1	30.5	28.8	28.5	23.1	28.4	27.0	27.7^{z}	1.89
Series 2	35.6	34.8	31.9	33.0	30.6	36.1	33.7^{y}	1.36
Warner-Bratzler shear force (N)								
Series 1	30.8	34.8	32.4	31.2	33.1	37.3	33.3^{y}	1.81
Series 2	28.5	27.9	30.5	28.8	27.3	26.1	28.2^{z}	1.28
M. *biceps femoris*								
Collagen (mg/100 g wet weight)								
Series 1	594^{abc}	695^{a}	615^{ab}	539^{bc}	511^{bc}	488^{c}	574^{z}	26.9
Series 2	677^{a}	604^{ab}	680^{a}	638^{a}	495^{c}	529^{bc}	604^{y}	22.4
Collagen solubility (%)								
Series 1	35.0^{a}	26.5^{b}	32.8^{ab}	31.1^{ab}	28.1^{b}	29.0^{ab}	30.4	1.54
Series 2	33.8^{a}	33.2^{a}	33.4^{a}	31.4^{ab}	26.5^{bc}	25.3^{c}	30.6	1.43
Warner-Bratzler shear force (N)								
Series 1	33.2^{b}	46.0^{a}	38.0^{ab}	40.8^{ab}	37.6^{ab}	34.4^{ab}	38.4^{y}	2.88
Series 2	28.8^{bc}	32.1^{abc}	38.0^{a}	34.4^{ab}	35.0^{ab}	25.8^{c}	32.4^{z}	1.91

[1]Means within one line without a common superscript differ significantly ($P<0.05$); series averages within the same variable with different superscripts are significantly different ($P<0.05$).

4. Discussion

4.1 Realized contents of intramuscular fat in steers fed on a forage-based diet

Steers of four out of the six beef breeds evaluated were able to reach on average a target level of 3.5 % IMF in the M.l.d. which was desired in order to ensure the favourable impression of marbling (CHAMBAZ et al., 2001). However, no single PI and BL steer was able to reach this target level although age was almost twice as high as in AN when fattening was finally terminated (CHAMBAZ et al., 2001). This illustrates that some cattle breeds obviously do not have the inherent ability to deposit increasing amounts of IMF regardless of the length of the fattening period, although carcass fatness is still increasing in this period (SMITH, 1988). Most other breeds show a widely linear increase not only in adipose tissue but also in IMF up to high slaughter ages as described for instance by SZÜCS et al. (2001a, 2001b) for German SI bulls. The high variability between animals of the same breed group in IMF content probably was mainly due to the restricted accuracy of the ultrasound method of IMF determination in live animals. However previous attempts analysing biopsies, as

another potential way of estimation, proved to be far less precise because of the inhomogeneity of the distribution of fat in the muscle.

4.2 Differences in meat quality of steers of different breed fattened to a target IMF level

As expected there was an antiparallel relationship of the breed group differences in IMF and other compositional traits. The differences in chemical composition of muscle between BL and PI on one hand with low IMF and AN, SI, CH and LI on the other hand are in accordance with the results of BROWNING et al. (1990) who reported that muscles of leaner carcasses were higher in water and protein content. Nevertheless, the close inverse relationship between moisture and fat content described by these authors and others (VAN KOEVERING et al., 1995) was less clear in the present study, especially in the M.b.f. where variations in IMF content were more associated with variations in protein content. This is probably due to the deliberately low differences in IMF. Accordingly, breed group differences in muscle protein and fat content were of very low importance in a dietetic sense. This is also true for muscle cholesterol content which was similar in all groups. Even muscles differed only slightly but equally by about 2–3 mg/100 g muscle tissue. This is in accordance with the results found by EICHORN et al. (1986), BAKER and LUNT (1990) as well as GARIEPY et al. (1999). RHEE et al. (1982) observed only a significant difference when comparing seven marbling-score categories when muscles "practically devoid" of marbling were compared with higher marbling scores which had higher cholesterol levels. However this contradicts findings of SLOVER et al. (1987) and VAN KOEVERING et al. (1995) reporting a positive relationship between fat and cholesterol content of raw beef. BROWNING et al. (1990) also noted a trend towards higher cholesterol levels from lean to fatter carcasses, but the difference of only 1.8 mg cholesterol/100g raw meat found is of little practical importance. Probably based on its low IMF content, there is a frequently cited opinion that meat of PI cattle has a considerably lower cholesterol content than meat of other breeds (MONTANA RANGE, 2001). However, neither the present data, where PI steers had been fattened to untypically high IMF contents for this breed, nor other scientific studies (BAKER and LUNT, 1990; GARIEPY et al., 1999; RULE et al., 1999) found any clear differences in muscle cholesterol between PI or PI crosses and other breeds.

Although PSE meat is not a major problem in beef, DUFEY (1987, 1988b, 1989) occasionally recorded too low pH_1-values in meat of bulls fattened in a tied stall, whereas no PSE meat was found here even in series 1 where the animals were kept under the same housing conditions as in the studies cited. The absence of DCB in this study is not surprising. DCB is a result of a reduced glycogen content in the muscle prior to slaughter and is often associated with stress caused for instance by mixing cattle or shipping fatigue. The duration of transport to the slaughter plant did not exceed 1 hour. Moreover the use of steers instead of bulls reduced the probability of DCB as steers have lower stress susceptibility (WARRISS, 1990). In normal beef, p.m. glycolysis reduces pH to 5.8 or lower within 48 h (KREIKEMEIER, 1998; IMMONEN and PUOLANNE, 2000). In an ultimate pH range of 5.8–6.0, defined as borderline DCB, meat already tends to have an abnormal colour and an increased risk of spoilage, particularly when vacuum-packed (WARRIS, 1990), although quality is still intermediate between true DCB and normal beef (VOISINET et al., 1997). This

type of borderline dark cutters was found here in two out of 132 carcasses. Despite the low variation in pH, breed groups differed to a certain degree in water-holding capacity, meat colour and tenderness related items. The range in drip loss found in the present study was mostly favourable as a level of up to 4.5 % is still considered as acceptable (ENDER and AUGUSTINI, 1998) whereas higher rates are undesired in retail packaging and so impair the appearance of the product at sale. Muscle tissue of M.l.d. but not of M.b.f. from LI steers showed drip losses on average just at the acceptable limit, and several members of this group had too high drip losses from M.l.d. according to the threshold level given above. Cooking losses were highest in both muscles in AN steers. Accordingly, differences between breeds were not related between drip loss and cooking loss, except in PI. This can be explained by the different compartments of bound water being stressed by the procedures. Drip losses are passive losses which strongly depend on loosely-bound water only affected by gravity, whereas meat was subjected to mechanical and thermal stressors along with ageing (vacuum), freezing/thawing and cooking. Accordingly, no correlation between drip loss and cooking loss was noted earlier (HONIKEL, 1986). CROSS et al. (1984) and CROUSE et al. (1985) did not find a difference in cooking losses between AN, SI, CH and Hereford as well as between AN and SI, respectively. The level of cooking losses were about two-fold lower in our study compared to those found by GERHARDY et al. (1995) with meat from 16 and 20 months old bulls and still lower than those found in young heifers by SCHEEDER et al. (1996) of 24 % and 25 % for M.l.d. and M.b.f., respectively. However, variation in cooking methods might have played an important role in this respect.

Apart from marbling, meat colour influences the visual appeal of meat to retail purchasers (SHORTHOSE and HARRIS, 1991) and thus is an important criterion for purchase decision of the consumer (FRENCH et al., 2000). Consumers appear to prefer beef which is neither extremely pale nor dark, with the range of L* values between 34 and 40 being considered as normal (ENDER and AUGUSTINI, 1998). On this basis, the meat of some AN and CH steers can be judged as to be too pale. An increasing IMF content tends to increase meat lightness (SHORTHOSE and HARRIS, 1991; FRENCIA and MONVOISIN, 1993), but the differences between BL and PI on one hand and the four other breeds on the other hand were not consistent. Obviously some independent breed differences in lightness exist. Similar to the present study, LIBORIUSSEN et al. (1977) found a higher heme iron content of the M.l.d. of SI sires compared with LI, CH and BL. However, the LI meat was lighter than that of CH which was not the case in our study. Accordingly, the heme iron content, the effective part of the pigments of bovine meat (RENERRE, 1982), similarly varied between breeds as the L* value. Heme iron is also of interest for human nutrition because of its high bioavailability (VARNAM and SUTHERLAND, 1995). In this view, AN and, partially, CH beef is inferior to beef of the other breeds.

Overall, the animals of the present study provided a very tender M.l.d. applying the thresholds of 38 N in Warner-Bratzler shear force for very tender meat and of 45 N for tender meat as given by SHACKELFORD et al. (1991) and VAN KOEVERING et al. (1995) which were obtained under similar measurement conditions. In accordance with SCHEEDER et al. (1996), the differences in peak shear force found between M.l.d. and M.b.f. were low. Thus even the M.b.f., where shear forces were extremely low for PI and AN in series 2, could be used as steak instead of using it as lower priced

cuts, particularly when size of this cut is not limiting due to big sized carcasses. Only the M.b.f. of the SI in the first series had to be judged on average as too tough to be marketed as steak. However, SCHEEDER et al. (1996) noticed that peak shear force data provide little explanation for the collagen component of tenderness thus indicating that there might nevertheless exist clear differences in tenderness of both muscles.

There was no clear relationship between IMF content and shear force among breed groups. The residual variation in IMF content among the breeds after fattening to a similar IMF level was contrary to the repeatedly stated inverse relationship between IMF and shear force (AUGUSTINI and LÜDDEN, 1992; SHACKELFORD et al., 1994a). For instance PI meat in series 2 had the lowest IMF content and the lowest shear forces in both muscles. This is in accordance with SHACKELFORD et al. (1994b) who found that meat from PI crosses with AN or Hereford dams, despite having a lower IMF content as the steers in our study, showed the lowest shear force among eleven genetic groups including AN and CH. This finding is also well supported by TATUM et al. (1990) who compared Gelbvieh, Red AN and PI sires. BLUMER (1963) and DIKEMAN (1996) reported that IMF content is a poor predictor of tenderness and only accounts for 5 to 10 % of the variability in tenderness. WHEELER et al. (1996) also found an increase in tenderness at a common marbling end point when using PI crosses with various dams instead of twelve other breed sires. KOCH et al. (1976) observed a difference of less than 3 N in shear force among AN and CH on one hand and LI and SI on the other hand when data were adjusted to a similar slaughter age. Though statistically significant, the differences were small and the values remained in the acceptable range of tenderness. DUFEY (1987) compared tenderness of M.l.d. samples from bulls of purebred SI, SI with 75 % Red Holstein blood, pure-bred Brown Swiss and Brown Swiss with 25 % Holstein blood. The sensory analysis revealed that the SI bulls had the toughest meat apart from the Brown Swiss crosses, and an improvement in meat quality took place with a high Red Holstein blood proportion. In another study, DUFEY (1988a) compared SI and Brown steers, their crosses with AN, and Holstein in taste panel evaluations of tenderness for M.l.d. and M. *semimembranosus* samples with the result that meat from SI steers was rated low in tenderness. Crossbreeding with AN positively influenced tenderness. In a third study, DUFEY (1989) compared tenderness of M.l.d. samples from F1 bulls sired by SI and BL with various dams (SI, Brown Swiss, Holstein). No significant differences were found in tenderness between the sire groups. BRANSCHEID and HERZOG (1996) noted that crossbreeding of German SI with CH and PI improved tenderness (shear force and panel tenderness). According to this trend described in literature, the present data also showed a higher shear force of meat of SI steers compared to the other breed groups but this tendency was only apparent in the first series.

4.3 Fattening series differences in meat quality of steers (tied housing vs loose housing)

Steers of the present study originated from two different fattening series, and housing system was changed from a tied system to group housing on straw beds without change in the diet. The statistical evaluation of the data revealed several effects of fattening series on meat quality. In detail, the IMF content was higher, the cooking

losses were clearly lower, collagen solubility in M.l.d. was higher and, finally, shear force was lower in series 2. From the design chosen, no clear attribution of the effects to housing system is possible and time-dependent effects as well as random trends in the animals selected from the breeds cannot be excluded. However, based on the results of other studies, some of the effects might nevertheless be explained by the variation in the housing situation. Using the tie-stall barn in series 1 resulted in a restricted movement and subsequent joint and leg problems which reduced growth rate at the end of fattening for the oldest animals (CHAMBAZ et al., 2001). Management practices which alter growth and muscle accretion rates can have a profound effect on muscle proteinases and collagen characteristics. An improved growth rate may result in a decreased calpastatin activity at 24-31 h p.m. and consequently in an improved tenderness (SHACKELFORD et al., 1994b). THOMPSON et al. (1996) found that meat from steers growing fastest prior to slaughter was more tender and had higher μ-calpain and calpastatin activities 2 h p.m. They concluded that a high μ-calpain activity is likely to be related to a high rate of protein degradation and this should result in an increase of the myofibrillar fragmentation index and, therefore, tenderness. From their study they presumed that the level of μ-calpain activity close to slaughter had been more important in determining tenderness than the calpastatin activity at 2 h p.m. Fast-growing cattle would also have a more intense protein turnover and therefore fewer heat-stable intermolecular collagen crosslinks (FISHELL et al., 1985; MCCORMICK, 1994). This could partly explain the higher collagen solubility and the lower shear force in series 2 in all breed groups. As collagen solubility was higher in M.l.d. in series 2, but not in M.b.f., certain additional series differences in the animals selected can be assumed. SI and PI had the highest series difference in slaughter age (63 days and 45 days younger in series 2 than in series 1, respectively; CHAMBAZ et al., 2001) and simultaneously showed the highest improvement of shear forces in series 2. Although the increase in the toughness of meat with animal age is well known (SHORTHOSE and HARRIS, 1990) it can be assumed that these effects were not determined by age alone. Firstly, all breed groups showed a decrease in shear force even those which were older in series 2 than in series 1 such as AN, CH and LI (25, 23 and 9 days older in series 2). Secondly, there were no significant correlations between age and shear forces within breed groups and series (data not shown). However from the age-related changes in collagen properties, nevertheless a certain decrease in tenderness with age can be expected. It is difficult to explain the better water-holding capacity found in series 2 by a single factor since animal genetics, age and slaughter conditions are known to significantly contribute to the expression of variations in these traits.

5. Conclusions

The overall goal of the present study was to compare a wide range in beef breeds in their differences in meat quality when a constant IMF content of 3.5 % is achieved. The target level in IMF, however, excluded two breeds, namely PI and BL, as not appropriate for this attempt. In the other four breeds, the target was reached on average but individual variation in IMF was still high within breed due to the restricted accuracy of the *in vivo* ultrasound method applied for determination. From the present material, without further attempt to reduce variability in IMF content, certain breed differences in important quality traits such as colour, water-holding capacity and

tenderness-related variables were found. Differences were particularly high between AN and the other suitable breeds (SI, CH, LI) with unfavourable properties of AN beef in total water-holding capacity and favourable estimates for tenderness-related data. However, differences in shear force among breed groups were small, with all breed groups being well above minimum levels of acceptance, even in a basically tougher muscle such as the M.b.f., except in SI. The significantly better growth characteristics obtained in the steers of the loose housing system compared with those in the tie-stall barn seemed to be the major cause of the improvement in meat quality in the second series. Apart from the inability of the BL and PI to reach a high IMF content under the present feeding and housing conditions, all breeds were suitable for premium beef quality marketing.

Acknowledgements

This study was financially supported by SVAMH (Schweizerische Vereinigung der Ammen- und Mutterkuhhalter), Brugg, Switzerland, and Proviande, Berne, Switzerland.

References

AOAC:
Official methods of analysis. 16th edition, method 988.05, chapter 4, (1995), p.5

ARNETH, W.; HAMM, R.:
Untersuchungen zur Methodik der Hydroxyprolinbestimmung in Fleisch und Fleischwaren. Fleischwirtsch. **10** (1971), 1523-1526

AUGUSTINI, C.; LÜDDEN, L.:
Rindfleischqualität - Bewertung des Endproduktes. Mittbl. Bundesanstalt Fleischforschung, Kulmbach **116** (1992), 121-125

BAKER, J.F.; LUNT, D.K.:
Comparison of production characteristics from birth through slaughter of calves sired by Angus, Charolais or Piedmontese bulls. J. Anim. Sci. **68** (1990), 1562-1568

BARTON, P.A.:
Measurement of colour stability of cooked cured meats to light and air. 1. Development of method. J. Sci. Food Agric. **18** (1967), 298-307

BLUMER, T.N.:
Relationship of marbling to the palatability of beef. J. Anim. Sci. **22** (1963), 771-778

BOEHRINGER MANNHEIM:
Methoden der enzymatischen Bioanalytik und Lebensmittelanalytik mit Testkombinationen. Boehringer Mannheim Biochemica (1994), Ref. 139050, 27-30

BOISSY, A.; TRILLAT, G.; FERNANDEZ, X.; BOIVIN, X.; SAPA, J.; CULIOLI, J.; LE NEINDRE, P.:
Réactivité comportementale et indicateurs de qualité de la viande chez le taurillon. In: Renc. Rech. Ruminants. INRA (Editor), Paris (2000), 58-61

BROWNING, M.A.; HUFFMAN, D.L.; EGBERT, W.R.; JUNGST, S.B.:
Physical and compositional characteristics of beef carcasses selected for leanness. J. Food Sci. **55** (1990), 9-14

BRANSCHEID, W.; CLAUS, R:
Markenfleisch. Von der Anonymität zum Qualitätsprodukt. In: Fleisch und Wurst. Bedeutung in der Ernährung des Menschen. Bundesanstalt für Fleischforschung Kulmbach, Germany (Editor), Kulmbacher Reihe 9 (1989), 33-46

BRANSCHEID, W.; HERZOG, R.:
Gebrauchskreuzung bei Fleckvieh. Eine Möglichkeit zur Beeinflussung der Fleischqualität. Jahresbericht 1996, Bundesanstalt für Fleischforschung Kulmbach (1996), 13-16

CHAMBAZ, A.; MOREL, I.; SCHEEDER, M. R. L.; KREUZER, M.; DUFEY, P.-A.:
Characteristics of steers of six beef breeds fattened from eight months of age and slaughtered at a target level of intramuscular fat. 1. Growth performance and carcass quality. Arch. Anim. Breed., Dummerstorf **44** (2001), 395-411

CROSS, H.R.; CROUSE, J.D.; MACNEIL, M.D.:
Influence of breed, sex, age and electrical stimulation on carcass and palatability traits of three bovine muscles. J. Anim. Sci. 58 (1984), 1358-1365
CROUSE, J.D.; CROSS, H.R.; SEIDEMAN, S.C.:
Effects of sex condition, genotype, diet and carcass electrical stimulation on the collagen content and palatability of two bovine muscles. J. Anim. Sci. 60 (1985), 1228-1234
DIKEMAN, M.E.:
The relationship of animal leanness to meat tenderness. In: Proc. 49th Ann. Recipr. Meat Conf., Chicago, Illinois, USA (1996), 87-101
DUFEY, P.-A.:
Qualité de la viande chez les taurillons. Revue suisse Agric. 19 (1987), 204-207
DUFEY, P.-A.:
Fleischqualität von Ochsen im Test, ein Vergleich von verschiedenen Rassen bei extensiver Weidemast. Landwirtsch. Schweiz 1 (1988a), 187-191
DUFEY, P.-A.:
Fleischqualität von Jungmuni im Test: ein Vergleich von verschiedenen Rassen bei Stallmast. Landwirtsch. Schweiz 1 (1988b), 337-341
DUFEY, P.-A.:
Vergleich der Fleischleistung von Blonde d'Aquitaine- und Simmentaler M-Gebrauchskreuzungen. 2 Teil. Fleischqualität. Landwirtsch. Schweiz 2 (1989), 477-482
DUFEY, P.-A.; CHAMBAZ, A.:
Einfluss von Produktionsfaktoren auf die Rindfleischqualität. Agrarforsch. 6 (1999), 345-348
EICHORN, J.M.; COLEMAN, L.J.; WAKAYAMA, E.J.; BLOMQUIST, G.J.; BAILEY, C.M.; JENKINS, T.G.:
Effects of breed type and restricted versus ad libitum feeding on fatty acid composition and cholesterol content of muscle and adipose tissue from mature bovine females. J. Anim. Sci. 63 (1986), 781-794
ENDER, K.; AUGUSTINI, C.:
Schlachttierwert von Rind und Kalb. In: Qualität von Fleisch und Fleischwaren. W. BRANSCHEID, K. O. HONIKEL, G. VON LENGERKEN and K. TROEGER (Editors), Deutscher Fachverlag, Frankfurt am Main (1998), 165-203
FISHELL, V.K.; ABERLE, E.D.; JUDGE, M.D.; PERRY, T.W.:
Palatability and muscle properties of beef as influenced by preslaughter growth rate. J. Anim. Sci. 61 (1985), 151-157
FRENCH, P.; O'RIORDAN, E.G.; MONAHAN, F.J.; CAFFREY, P.J.; VIDAL, M.; MOONEY, M.T.; TROY, D.J.; MOLONEY, A.P.:
Meat quality of steers finished on autumn grass, grass silage or concentrate-based diets. Meat Sci. 56 (2000), 173-180
FRENCIA, F.R.; MONVOISIN, D.:
Mesure objective de la couleur des carcasses de gros bovins. Viandes Prod. Carnés 14 (1993), 160-164
GARIEPY, C.; SEOANE J.R.; CLOTEAU C.; MARTIN J.F.; ROY G.L.:
The use of double-muscled cattle breeds in terminal crosses: Meat quality. Can. J. Anim. Sci. 79 (1999), 301-308
GERHARDY, H.:
Untersuchung einer marktorientierten Fleischerzeugung auf der Basis von Schwarzbunten Jungbullen und Fleckvieh-, Limousin- und Weiss-blaue Belgier-Kreuzungen. Züchtungskunde, Stuttgart 66 (1994), 281-296
GERHARDY, H.; KREUZER, M.; LANGHOLZ, H.-J.:
Untersuchungen zur Erzeugung von Qualitätsrindfleisch mit schwarzbunten Jungbullen in Mastverfahren mit unterschiedlicher Mastdauer und -intensität. Züchtungskunde, Stuttgart 67 (1995), 117-131
HONIKEL, K.O.:
Wasserbindungsvermögen von Fleisch. In: Chemisch-physikalische Merkmale der Fleischqualität. Band 6. Institut für Chemie und Physik (Editor), Kulmbach (1986), 67-88
HONIKEL, K.O.:
Reference method for the assessment of physical characteristics of meat. Meat Sci. 49 (1998), 447-457
IMMONEN, K.; PUOLANNE, E.:
Variation of residual glycogen-glucose concentration at ultimate pH values below 5.75. Meat Sci. 55 (2000), 279-283
KASTNER, C.L.; HENRICKSON, R.L.:
Providing uniform meat cores for mechanical shear force measurement. J. Food Sci. 34 (1969), 603-605
KOCH, R.M.; DIKEMAN, M.E.; ALLEN, D.M.; MAY, M.; CROUSE, J.D.; CAMPION, D.R.:
Characterization of biological types of cattle. III. Carcass composition, quality and palatability. J. Anim. Sci. 43 (1976), 48-62

KOPP, J.; SALE, P.; BONNET, Y.:
Contractomètre pour l'étude des propriétés physiques des fibres conjonctives: tension isométrique, degré de réticulation, relaxation. J. Can. Inst. Food Sci. Technol. 10 (1977), 69-72
KREIKEMEIER, K.K.; UNRUH, J.A.; ECK, T.P.:
Factors affecting the occurrence of dark-cutting beef and selected carcass traits in finished beef cattle. J. Anim. Sci. 76 (1998), 388-395
LIBORIUSSEN, T.; ANDERSEN, B.B.; BUCHTER, L.; KOUSGAARD, K.; MØLLER, A.J.:
Crossbreeding experiment with beef and dual-purpose sire breeds on Danish dairy cows. IV. Physical, chemical and palatability characteristics of longissimus dorsi and semitendinosus muscles from crossbred young bulls. Livest. Prod. Sci. 4 (1977), 31-43
MCCORMICK, R. J.:
The flexibility of the collagen compartment of muscle. Meat Sci. 36 (1994), 79-91
MONTANA RANGE:
Nutritional comparison. Montana Range Brand Meat home page. Available at: http://www.montanarange.com/benefits_frameset.html (2001). Accessed Apr. 5, 2001
NAUMANN, K.; BASSLER, R.:
Die chemische Untersuchung von Futtermitteln. Vol. III., VDLUFA-Verlag, Darmstadt (1997)
NEUMANN, W.; MARTIN, J.:
Schlachtkörperzusammensetzung und Fleischqualität bei verschiedenen Genotypen. In: Beef Carcass and Meat Quality Evaluation. Proc. Satellite Symp. 42. EAAP Symp. K. Ender (Editor), Research Center of Animal Production, Dummerstorf-Rostock (1991), 26-32
RENERRE, M.:
La couleur de la viande et sa mesure. Bull. Techn. CRZV Theix INRA 47 (1982), 47-54
RHEE, K.S.; DUTSON, T.R.; SMITH, G.C.; HOSTETLER, R.L.; REISER, R.:
Cholesterol content of raw and cooked beef longissimus muscles with different degrees of marbling. J. Food Sci. 47 (1982), 716-719
ROCHE, B.; DEDIEU, B.; INGRAND, S.:
Analyse comparative des cahiers des charges Label Rouge gros bovins de boucherie. In: Renc. Rech. Ruminants. INRA (Editor), Paris (2000), 259-262
RULE, D.C.; SHORT, R.E.; GROSZ, M.D.; MacNEIL, M.D.:
Breed effects on cholesterol and fatty acids in longissimus muscle of Hereford, Limousin, and Piedmontese F2 crossbred cattle at slaughter. In: 91st Ann. Meet. Abstracts. American Society of Animal Science (Editor), Indianapolis, Indiana, USA 77 Suppl. 1 (1999), 166
SCHEEDER, M.R.L.; GERHARDY, H.; LANGHOLZ, H.-J.:
Untersuchungen zur Verwertungseignung unterschiedlicher Muskeln weiblicher Jungmastrinder. Arch. Anim. Breed., Dummerstorf 39 (1996), 415-429
SHACKELFORD, S.D.; MORGAN, J.B.; CROSS, H.R.; SAVELL, J.W.:
Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2 (1991), 289-296
SHACKELFORD, S.D.; KOOHMARAIE, M.; WHEELER, T.L.:
The efficacy of adding a minimum adjusted fat thickness requirement to the USDA beef quality grading standards for Select Grade beef. J. Anim. Sci. 72 (1994a), 1502-1507
SHACKELFORD, S.D.; KOOHMARAIE, M.; CUNDIFF, L.V.; GREGORY, K.E.; ROHRER, G.A.; SAVELL, J.W.:
Heritabilities and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retail product yield, and growth rate. J. Anim. Sci. 72 (1994b), 857-863
SHORTHOSE, W. R.; HARRIS, P. V.:
Effect of animal age on the tenderness of selected beef muscles. J. Food Sci. 55 (1990), 1-7
SHORTHOSE, W.R.; HARRIS, P.V.:
Effects of growth and composition on meat quality. In: Growth Regulation in Farm Animals. A. M. PEARSON and T. R. DUTSON (Editors), Elsevier Applied Science, London and New York (1991), 515-555
SLB:
Schweizerisches Lebensmittelbuch, erster Band - allgemeiner Teil. 5th edition, Eidg. Drucksachen- und Materialzentrale, Berne, Switzerland (1969)
SLOVER, A.T.; LANZA, E.; THOMPSON, R.H.JR.; DAVIS, C.S.; MEROLA, G.V.:
Lipids in raw and cooked beef. J. Food Comp. Anal. 1 (1987), 26-37
SMITH, G.C.:
Possible impacts of changes on USDA grade standards and labeling. In: Designing Foods, Animal Product Options in the Marketplace. National Research Council (Editor), National Academy Press, Washington, D.C., USA (1988), 332-344

SZÜCS, E.; ENDER, B.; PAPSTEIN, H.-J.; NÜRNBERG, G.; ENDER, K.:
Vergleich des Schlacht- und Nährwertes sowie der Fleischbeschaffenheit von Jungbullen der Rassen Deutsches Fleckvieh und Deutsche Holsteins (Schwarzbunte) im Verlauf des Wachstums. 1. Mitt.: Wachstum und Schlachtkörperzusammensetzung. Züchtungskunde, Stuttgart 73 (2001a), 33-44

SZÜCS, E.; ENDER, B.; PAPSTEIN, H.-J.; NÜRNBERG, G.; ENDER, K.:
Vergleich des Schlacht- und Nährwertes sowie der Fleischbeschaffenheit von Jungbullen der Rassen Deutsches Fleckvieh und Deutsche Holsteins (Schwarzbunte) im Verlauf des Wachstums. 2. Mitt.: Nährwert und Fleischbeschaffenheit. Züchtungskunde, Stuttgart 73 (2001b), 45-53

TATUM, J.D.; GRONEWALD, K.W.; SEIDEMAN, S.C.; LAMM, W.D.:
Composition and quality of beef from steers sired by Piedmontese, Gelbvieh and Red Angus bulls. J. Anim. Sci. 68 (1990), 1049-1060

TEMISAN, V.:
Qualitätssicherung in der Erzeugung und Vermarktung von Qualitätsrindfleisch. 1. Konzept der Gesamtqualität und der integrierten Qualitätssicherung. Fleischwirtsch. 70 (1990), 968-980

THOMSON, B.C.; DOBBIE, P.M.; BASS, J.J.; SINGH, K.; MUIR, P.D.:
Effect of growth path on the calpain system and shear force in Angus steers. In: Proc. 42nd ICoMST. Meat for the Consumer. MATFORSK (Publisher). Lillehammer, Norway (1996), 416-417

VAN KOEVERING, M.T.; GILL, D.R.; OWENS, F.N.; DOLEZAL, H.G.; STRASIA, C.A.:
Effect of time on feed on performance of feedlot steers, carcass characteristics, and tenderness and composition of longissimus muscles. J. Anim. Sci. 73 (1995), 21-28

VARNAM, A.H.; SUTHERLAND, J.P.:
Meat and meat products. Technology, chemistry and microbiology. 1st edition, CHAPMAN & HALL, London, UK (1995), p.8

VOISINET, B.D.; GRANDIN, T.; O'CONNOR, S.F.; TATUM, J.D.; DEESING, M.J.:
Bos indicus-cross feedlot cattle with excitable temperaments have tougher meat and a higher incidence of borderline dark cutters. Meat Sci. 46 (1997), 367-377

WARRISS, P. D.:
The handling of cattle pre-slaughter and its effects on carcass and meat quality. Appl. Anim. Behaviour Sci. 28 (1990), 171-186

WHEELER, T.L.; CUNDIFF, L.V.; KOCH, R.M.; CROUSE, J.D.:
Characterization of biological types of cattle (cycle IV): carcass traits and longissimus palatability. J. Anim. Sci. 74 (1996), 1023-1035

Received: 2001-04-20

Accepted: 2001-06-15

Authors' addresses
Dipl.-Ing. agr. ALAIN CHAMBAZ, Dipl.-Ing. agr. PIERRE-ALAIN DUFEY
Swiss Federal Research Station for Animal Production
CH-1725 Posieux
Switzerland

Prof. Dr. MICHAEL KREUZER*, Dr. MARTIN R. L. SCHEEDER
Institute of Animal Sciences, Animal Nutrition
ETH Zurich, ETH-Zentrum
CH-8092 Zurich
Switzerland

*Corresponding author