Effects of concentrate level and rapeseed meal supplementation on performance, carcass characteristics, meat quality and valuable cuts of Hereford and Charolais bulls offered grass silage-barley-based rations

Maiju Pesonen[1*], Markku Honkavaara[2], Helena Kämäräinen[3], Tiina Tolonen[4], Mari Jaakkola[4], Vesa Virtanen[4] and Arto Huuskonen[1]

[1] MTT Agrifood Research Finland, Animal Production Research, FI-92400 Ruukki, Finland

[2] Finnish Meat Research Institute, P.O. Box 56, FI-13101, Hämeenlinna, Finland

[3] University of Eastern Finland, Department of Biosciences, P.O. Box 1627, FI-70211 Kuopio, Finland

[4] University of Oulu, Kajaani University Consortium, CEMIS-Oulu, Salmelantie 43, FI-88600 Sotkamo, Finland

e-mail: maiju.pesonen@mtt.fi

The objectives of this experiment with Hereford (Hf) and Charolais (Ch) bulls offered grass silage-based diets were to determine the effects on performance, carcass traits and meat quality of the proportion of concentrate in the diet, and the inclusion of rapeseed meal (RSM) in the barley-based concentrate. The two concentrate proportions were 200 and 500 g kg^{-1} dry matter, fed without or with RSM. The Ch bulls tended to achieve higher gain, produced less fat, had a higher percentage of meat from high-priced joints and had a lower degree of marbling in their meat compared to the Hf bulls. Dry matter and energy intakes, growth performance and carcass conformation improved with increasing concentrate level. Intake parameters and conformation improved more with the Ch bulls than with the Hf bulls as a consequence of increased concentrate allowance. RSM had only limited effects on the performance, carcass traits or meat quality.

Key words: beef production, bulls, concentrate level, supplementary protein, performance, eating quality, meat fatty acids

Introduction

Although beef production in Finland is based mainly on raising dairy bulls, production from beef breed calves is increasing at present. In total, 12 beef breeds are currently kept, and Charolais (Ch) and Hereford (Hf) are the two most frequently used beef breeds. The decrease in the number of dairy cows has diminished the supply of calves for beef production originating from dairy herds. Because the supply of domestic beef has been decreasing, there is nowadays a clear discrepancy between the demand for and supply of domestic beef. Consequently, slaughterhouse pricing favours heavy carcasses and the average carcass weights of slaughtered animals have clearly increased in Finland during recent years. For example, the average carcass weight of slaughtered bulls (including both dairy and beef breeds) increased from 275 kg (1996) to 335 kg (2008) in twelve years (Karhula and Kässi 2010). Currently, it is typical that bulls of British beef breeds (Hereford, Angus) are slaughtered in carcass weights near 400 kg and late maturing beef breeds (Charolais, Simmental) in carcass weights above 400 kg (Huuskonen et al. 2012).

In intensive beef production, grass silage is typically supplemented with grain to increase the energy and nutrient intake of growing bulls. Rapeseed meal (RSM) is the most important protein feed used in concentrates for cattle. Nowadays many beef producers use protein supplements with grass silage grain- based feedings (Huuskonen 2009a) even though the price of RSM is high compared to those of grain or forages and feeding extra protein increased the N and P excretion to the environment (Klopfenstein and Erickson 2002).The effects of both concentrate level and protein supplementation on the performance of growing cattle have been extensively studied. It is well established that good quality silage can support high levels of performance with moderate concentrate supplementation. However, increasing the allowance of concentrate has often improved the growth rate and decreased the days until slaughter (e.g. Huuskonen et al. 2007, Randby et al. 2010). With dairy bulls it was concluded that concentrate with a higher protein concentration than barley grain is not needed when the animals are fed high- or medium-digestibility and restrictively fermented grass silage and barley-based concentrate (Huuskonen et al. 2007, 2008b, Huuskonen 2009b, 2011). Relative to dairy bulls, much less research has been carried out on the feeding of beef bulls and, in fact, there is lack of information on the effects of concentrate proportions and protein supplementation on the performance, carcass traits and meat quality of beef-breed bulls offered typical Finnish grass silage-barley-based rations and slaughtered with high carcass weights.

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Meat quality aspects are receiving considerable attention among consumers. For example, meat colour is an important determinant of the visual appearance of meat, with light coloured beef often being preferred, although some consumers may favour dark beef associating this appearance with a more natural production method (Razminowicz et al. 2006). Tenderness and marbling are important properties of beef for consumers and have been studied widely. Nevertheless, studies on the effects of concentrate level and protein supplementation with grass silage-barley-based rations on eating quality are scarce. In addition, the fatty acid composition of beef has received considerable attention in view of its implications for human health and for meat quality characteristics (De Smet et al. 2004). The objectives of the present experiment with growing Hf and Ch bulls were to determine the effects on animal performance, carcass characteristics, valuable cuts, meat quality parameters and fatty acid composition of the *Longissimus* muscle of (1) the proportion of concentrate in the diet, and (2) the inclusion of RSM in the barley-based concentrate fed in total mixed rations (TMR) when animals are slaughtered at typical Finnish carcass weights.

Materials and methods

Animals and housing

The feeding experiment was conducted in the experimental barn of the North Ostrobothnia Research Station of MTT Agrifood Research Finland (Ruukki, 64°44'N, 25°15'E) and included three trials. The first trial started in December 2008, the second in January 2010 and the third in January 2011. The experimental procedures were evaluated and approved by the Animal Care and Use Committee of MTT Agrifood Research Finland. The three feeding trials comprised in total 48 purebred Hf bulls (Hf dams sired by Hf bulls) and 48 purebred Ch bulls (Ch dams sired by Ch bulls) in order that there were 32 bulls per trial. Diet *in vivo* digestibility, animal performance (intake and gain) and carcass characteristics (carcass weight, dressing proportion, conformation score and fat score) were determined in all three trials, the meat quality parameters and valuable cuts were measured in the second and third trial. Two bulls were excluded from the study due to several occurrences of bloat, one due to pneumonia and three bulls due to hoof problems. There was no reason to suppose that the diets had caused these problems. The records of the six removed animals were not included in the results.

All the animals, initial live weight (LW) 306 ± 97.9 kg (Hf) and 333 ± 63.1 kg (Ch), on average, were spring-born calves purchased from commercial suckler herds. During their first summer all the calves had been kept on pasture together with their dams. At the start of the experiment the animals were 195 ± 55.6 days old, on average, and there was no difference between breeds. During the feeding experiment the bulls were placed in an insulated barn in adjacent tie-stalls. The width of the stalls was 70–90 cm for the first four months and 113 cm until the end of the experiment. The bulls were tied with a collar around the neck, and a 50 cm long chain was attached to a horizontal bar 40–55 cm above the floor. The floor surface was solid concrete under the forelegs and metal grids under the hind legs. No bedding was used on the floor. Each bull had its own water bowl.

Feeding and experimental design

The bulls were fed a TMR *ad libitum* (proportionate refusals of 5%). A 2×2×2 factorial design was used to study the effects of concentrate proportion and RSM inclusion in the barley-based concentrate. Both Hf and Ch bulls were randomly allotted to the experimental feeding treatments. The two concentrate proportions were 200 (L) and 500 (M) g kg^{-1} DM, fed without RSM (RSM−) or with RSM (RSM+). The concentrate used was rolled barley. Rapeseed meal was given so that the crude protein (CP) content of the concentrate was raised to 160 g kg^{-1} DM in the RSM+ diets. Therefore the amount of RSM supplement depended on the CP content of the barley which was measured by chemical analyses. In the RSM− diets the average CP content of the concentrate was 126 g kg^{-1} DM, so the content increased 27% with RSM supplementation.

The grass silages in all three trials were growth from mixed timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*) stands and were cut using a mower conditioner, wilted for 5 h, and harvested using a precision-chop forage harvester. The grass silages were ensiled in bunker silos and treated with a formic acid-based additive (AIV-2 Plus: 760 g formic acid kg^{-1}, 55 g ammonium formate kg^{-1}, supplied by Kemira Ltd., P.O. Box 171, FI-90101 Oulu, Finland) applied at a rate of 5 litres t^{-1} of fresh grass. The daily ration for the bulls included also 150 g of a mineral mixture (A-Rehu Ltd., P.O. Box 908, FI-60061 Atria, Finland: KasvuApeKivennäinen: Ca 260, P 0, Na 70, Mg 35 g kg^{-1}). A vitamin mixture (Suomen Rehu Ltd.: Xylitol ADE-Vita: A 2,000,000 IU kg^{-1}, D_3 400,000 IU kg^{-1}, E DL-α-tocopheryl acetate 1,000 mg kg^{-1}, E DL-α-tocopheryl 900 mg kg^{-1}, Se 10 mg kg^{-1}) was given at 50 g per animal weekly.

Feed and faecal sampling and analysis

Silage sub-samples for chemical analyses were taken twice a week, pooled over periods of four weeks and stored at –20°C. Thawed samples were analysed for DM, ash, crude protein (CP), ether extracts, neutral detergent fibre (NDF), indigestible NDF (iNDF), starch, silage fermentation quality (pH, water-soluble carbohydrates [WSC], lactic and formic acids, volatile fatty acids, soluble and ammonia N content of N) and digestible organic matter (DOM) in DM (D value). Concentrate sub-samples were collected weekly, pooled over periods of eight weeks and analysed for DM, ash, CP, ether extracts, NDF, iNDF and starch. The analyses were performed as described by Huuskonen et al. (2008a).

The metabolizable energy (ME) contents of the feeds were calculated according to the Finnish feed tables (MTT 2012). The ME value of the silage was calculated as 0.016 × D value. The ME values of the concentrates were calculated based on concentrations of digestible crude fibre, CP, crude fat and nitrogen-free extract described by MAFF (1984). The digestibility coefficients of the concentrates were taken from the Finnish feed tables (MTT 2012). The supply of amino acids absorbed from the small intestine (AAT) and the protein balance in the rumen (PBV) were calculated according to the Finnish feed tables (MTT 2012).

Because the grass silages used in the feeding experiment came from three different harvests, the chemical compositions and feeding values are also given separately for the three silages in Table 1. The silages used were of good nutritional quality as indicated by the D value as well as the AAT and CP contents (Table 1). The fermentation characteristics of the silages were also good as indicated by the pH value and the low concentration of ammonia N and total acids. The silages used were restrictively fermented with high residual WSC concentration and low lactic acid concentration. Because the chemical compositions and feeding values of the barley grain and RSM were very uniform throughout the experiment, only the mean values over the trials are given for barley and RSM in Table 1.

Table 1. Chemical composition and feeding values of barley, rapeseed meal and grass silages.

	Silage trial 1	Silage trial 2	Silage trial 3	Silage mean (trials 1, 2, 3)	Barley	Rapeseed meal
N [a]	16	13	9	38	19	19
Dry matter (DM), g kg^{-1} feed	252	300	343	298	885	881
Organic matter (OM), g kg^{-1} DM	937	936	918	930	975	927
Crude protein, g kg^{-1} DM	164	128	161	151	126	341
Neutral detergent fibre (NDF), g kg^{-1} DM	558	574	523	552	241	331
Indigestible NDF, g kg^{-1} DM	60	51	56	56	43	133
Ether extract, g kg^{-1} DM	39	35	38	37	16	44
Starch, g kg^{-1} DM	14	7	8	10	524	30
Metabolizable energy, MJ kg^{-1} DM	10.8	10.5	10.9	10.7	13.1	11.7
AAT [c], g kg^{-1} DM	85	79	84	83	101	151
PBV [d], g kg^{-1} DM	20	-1	37	19	-32	111
Digestible OM in DM, g kg^{-1} DM	678	654	683	672	ND [b]	ND
Fermentation quality of silage						
pH	4.06	4.04	4.56	4.22		
Volatile fatty acids, g kg^{-1} DM	18	18	17	18		
Lactic + formic acid, g kg^{-1} DM	53	48	30	44		
Water soluble carbohydrates, g kg^{-1} DM	47	67	101	72		
In total N, g kg^{-1}						
NH_4N	69	73	65	69		
Soluble N	534	540	511	528		

[a] Number of feed samples. Silage: values of three trials are given separately. Other feeds: only mean values over the trials are given because the chemical compositions and feeding values were very uniform throughout the experiment.
[b] Not determined.
[c] Amino acids absorbed from small intestine.
[d] Protein balance in the rumen.

Diet digestibility was determined for all animals when the bulls were 580 ± 61 kg LW, on average. Feed and faecal samples were collected twice a day (at 7:00 a.m. and 3:00 p.m.) during the collection period (5 d) and stored frozen prior to analyses. The samples were analyzed for DM, ash, CP and NDF as described above. The diet digestibility was determined using acid-insoluble ash (AIA) as an internal marker (Van Keulen and Young 1977).

Live weight, slaughter procedures and meat quality measurements

The animals were weighed on two consecutive days at the beginning of the trials and thereafter approximately every 28 days. Before slaughter they were weighed on two consecutive days. The target for average carcass weight in the experiment was 380 kg for Hf bulls and 420 kg for Ch bulls which are nowadays the average slaughter weights for Hf and Ch bulls in Finland (Huuskonen et al. 2012). The animals were selected for slaughter based on LW and assumed dressing proportions (0.530 for Hf bulls and 560 for Ch bulls) which were assessed based on earlier studies (unpublished data) in Finland with beef-breed bulls. The LWG was calculated as the difference between the means of initial and final live weights divided by the number of growing days. The estimated rate of carcass gain was calculated as the difference between the final carcass weight and the carcass weight in the beginning of the experiment divided by the number of growing days. The carcass weight at the start of the experiment was assumed to be 0.50 × initial LW, which was assessed based on earlier studies (unpublished data).

The animals were slaughtered in the Atria commercial slaughterhouse in Kuopio, 265 km from the Research Station. After slaughter the carcasses were weighed hot. The cold carcass weight was estimated as 0.98 of the hot carcass weight. Dressing proportions were calculated from the ratio of cold carcass weight to final LW. The carcasses were classified for conformation and fatness using the EUROP quality classification (EC 2006). For conformation, the development of the carcass profiles, in particular the essential parts (round, back, shoulder), was taken into consideration according to the EUROP classification (E: excellent, U: very good, R: good, O: fair, P: poor) and for fat cover degree, the amount of fat on the outside of the carcass and in the thoracic cavity was taken into account using a classification range from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). Each level of the conformation scale was subdivided into three sub-classes (O+, O, O-) to produce a transformed scale ranging from 1 to 15, with 15 being the best conformation.

After classification carcasses were chilled overnight below 7 °C. Day after slaughter the right side of carcasses were commercially cutted. Primal cuts were forequarter, back, side and round. The right side of each carcass was cut into valuable cuts [outside round (*Musculus semitendinosus*), inside round (*Musculus semimembranosus*), corner round (*Musculus quadriceps femoris*), roast beef (*Musculus gluteus medius*), tenderloin (*Musculus psoas major*), loin (*Musculus longissimus lumborum*) and entrecote (*Musculus longissimus thoracis*)], subcutaneous fat and bones as described by Manninen et al. (2011). All cuttings, subcutaneous fat and bones were weighed and their yields were expressed as percentages of the cold carcass weight (0.98 × hot carcass weight, 50 min *post mortem*). Forequarter was cutted into subcutaneous fat, bones, trimmings and entrecote (*Musculus longissimus thoracis* between the 4th and the 7th rib). Back was cutted into fat, bones, trimmings and loin (*Musculus longissimus lumborum* between the 7th rib and the 5th lumbar vertebra). Loin was cutted at the level of the 1st lumbar vertebra, and the achieved 2 kg loin sample between the 1st and the 5th lumbar vertebra was used for further analysis. The marbling score of entrecote (at the 7th rib) and loin (at the 1st lumbar vertebra) were evaluated by using a six-point scale (0=devoid to 5=abundant).

pH-value of the loin was measured with a Knick 651 instrument with Inlab Solid electrode (Mettler Toledo) at the level of the 1st lumbar vertebra. Meat color of the loin was measured after a bloom time of half an hour (Warris 1996) with a Minolta Cr-200 handheld chroma meter (Minolta Camera Co., Ltd., Osaka, Japan). The chroma meter had an 8 mm diameter measuring area, used diffuse illumination and 0º viewing angle geometry to provide accurate readings in a wide variety of color control applications. Before measurements Cr-200 was calibrated to a standard white plate, and CIE Standard Illuminant D65 conditions were used for the measurements. Readings were displayed in L*a*b* (L* luminance from 0 to 100; a* green to red from −60 to 60, respectively; and b* blue to yellow from −60 to 60, respectively). Each sample was measured three times and a mean value was calculated.

During cutting, a 2 kg loin sample was taken and vacuum packed. These samples were sent to the Finnish Meat Research Institute (LTK) for further analyses. Total ageing time of samples was 8 days at 4 °C. Thereafter samples were analysed for drip loss, moisture, protein and fat concentrations, Warner-Bratzler shear force and for tenderness, juiciness and beef flavour (sensory analysis). Drip loss was determined by the amount of water loss from the 2 kg loin sample after ageing. Moisture, protein and fat concentrations were determined as described by Huuskonen et al. (2010). For shear force measurements, loin samples were heated in a water bath at 85 °C until the core temperature of the meat was 70°C. After chilling for 24 hours (4 °C), loin samples about 6 cm long (parallel to the myofibres), 1 cm high and 1 cm wide (square probe of 1 cm × 1 cm surface area) were placed in a Warner-Bratzler shear blade to be sheared perpendicular to the longitudinal axis of the muscle fibres in an Instron testing machine. The maximum force was recorded and results were expressed as kg $(cm^{-2})^{-1}$ (Honkavaara et al. 2003) because the sheared meat sample had a height of 1.0 cm and a width of 1.0 cm and a length of 6.0 cm. Thus the shear force is expressed as kg per sheared surface area of 1.0 cm^2.

For the sensory analysis, surface fat was removed and trimmed loin was cut into four slices with thickness of 1.5 cm. After that these four samples were heated simultaneously up to internal temperature of 68 °C in a rolling grill (Palux Rotimat, Germany). Heated samples were served immediately in a sensory panel room with white lightning and temperature of 24 °C. Six trained sensory panelists evaluated the samples for tenderness, juiciness and beef flavour. These traits were scored on a seven-point scale (1 = very tough/very dry/very non beef like,..., 7 = very/tender/very juicy/very beef like).

Fatty acids were extracted from loin samples according to a slightly modified AOAC standard method (AOAC 2002) and methylated to corresponding fatty acid methyl esters (FAMEs) in hexane with 2M sodium hydroxide and 1M hydrochloride acid in methanol. FAMEs were analyzed using a gas chromatograph (Agilent 6850 Series) equipped with flame ionization detector by a previously published method (Jaakkola et al. 2012) with modified temperature program: the temperature was increased 25°C min^{-1} from 35°C to 190°C, and then by 3°C min^{-1} to 205°C and then to 220°C with 8°C min^{-1}, and finally held there for 22 min. FAMEs were identified by comparing samples with fatty acid standards GLC 461, UC-60M, U-48M, U-69M, U-99M, U-101M and U-84M (Nu-chek Prep Inc., Elysian, MN, USA). Methyl stearate (Sigma-Aldrich) was used for quantification purposes.

Statistical methods

The results were analysed across all three trials (results of meat quality and valuable cuts across two trials) and are shown as least squares means. The normality of analysed variables was checked using graphical methods: boxplot and scatter plot of residuals and fitted values. The data were subjected to analysis of variance using the SAS MIXED procedure (version 9.1, SAS Institute Inc., Cary, NC). The statistical model used was

$$y_{ijklm} = \mu + \delta_l + \alpha_i + \beta_j + \gamma_k + (\alpha\times\beta)_{ij} + (\alpha\times\gamma)_{ik} + (\beta\times\gamma)_{jk} + (\alpha\times\beta\times\gamma)_{ijk} + (\delta\times\alpha\times\beta\times\gamma)_{lijk} + e_{ijklm}$$

where μ is intercept and e_{ijklm} is the random error term associated with m^{th} animal. α_i, β_j and γ_k are the fixed effects of i^{th} breed (Hf, Ch), j^{th} concentrate level (200, 500) and k^{th} RSM supplementation (RSM−, RSM+), respectively. δ_l is random effect of l^{th} trial (l=1,2,3). $(\delta\times\alpha\times\beta\times\gamma)_{lijk}$ is random effect of trial-by-treatment which is used as an error term when differences between treatments (=breed, concentrate level, RSM supplementation) were tested.

Results

The average chemical compositions of the TMR used are presented in Table 2. Because of the higher energy and AAT contents of the concentrate, increasing the concentrate proportion increased the calculated energy and AAT values of the rations. Increasing the proportion of the concentrate also increased the starch content, but decreased the NDF content of the rations. The CP content of the L and M rations increased 8 and 12% with RSM supplementation, respectively (Table 2).

Diet digestibility, feed intake and growth performance

Significant, but numerically small, breed × concentrate level × RSM supplementation three-way interactions were observed for the DM, OM and NDF digestibilities (Table 3). Other interactions for digestibility variables between breed, concentrate level and RSM supplementation were not observed. Breed had no effects (p>0.05) on the diet digestibility coefficients (Table 3). Increasing the concentrate proportion led to improved DM (p<0.001), OM (p<0.001) and CP (p<0.01) apparent digestibilities. The digestibility of NDF decreased 3% with increasing concentrate proportion (p<0.001). Rapeseed meal supplementation had no effect on the DM, OM and NDF digestibilities, but the CP digestibility was 7% higher for the RSM+ diets than for the RSM−diets (p<0.001).

Table 2. Chemical compositions and nutritional values of total mixed rations used (mean values of three trials).

Concentrate proportion, g kg^{-1} dry matter (DM) [a]	L (200)	L (200)	M (500)	M (500)
Rapeseed meal supplementation	-	+	-	+
DM, g kg^{-1} feed	344	344	446	446
Organic matter, g kg^{-1} DM	939	937	953	949
Crude protein, g kg^{-1} DM	146	157	139	155
Neutral detergent fibre (NDF), g kg^{-1} DM	490	494	397	403
Ether extract, g kg^{-1} DM	33	34	27	28
Starch, g kg^{-1} DM	113	88	267	230
Metabolizable energy, MJ kg^{-1} DM	11.2	11.1	11.9	11.8
Amino acids absorbed from small intestine, g kg^{-1} DM	87	89	92	96
Protein balance in the rumen, g kg^{-1} DM	9	18	-7	7

[a] L = low concentrate proportion (200 g kg^{-1} DM); M = medium concentrate proportion (500 g kg^{-1} DM).

There were no differences in average DM, energy and CP intakes between Hf and Ch bulls (Table 3). Instead, increasing the level of concentrate led to higher DM (p<0.001), energy (p<0.001) and CP (p<0.01) intakes by the bulls whereas the supply of NDF decreased (p<0.001) with increasing concentrate level. There were also interactions (p<0.05) between the breed and the concentrate level for DM, energy and CP intakes. Intake increased more with the Ch bulls than with the Hf bulls as a consequence of increased concentrate level. The average supply of CP (p<0.001), AAT (p<0.05) and PBV (p<0.001) were higher when RSM was included in the diet, but RSM supplementation had no effect on the average DM or energy intake.

There were no significant interactions for live weight or gain variables between breed, concentrate level and RSM supplementation (Table 3). The mean final LW of the Hf and Ch bulls were 726 and 754 kg, respectively. The live weight gain and carcass gain of the Ch bulls were 10 and 22% higher than those of the Hf bulls, respectively (p<0.001). Increasing the proportion of concentrate led to an improvement of daily LWG and carcass gain of the bulls (p<0.001). The RSM supplementation had no effect on growth performance, but LWG and carcass gain of the bulls tended to be 5% lower on RSM− diets than on RSM+ diets (p=0.08).

There were no interactions for feed conversion variables between breed, concentrate level and RSM supplementation. Feed conversion (kg DM kg^{-1} carcass gain) and energy conversion rates (MJ ME kg^{-1} carcass gain) improved 14 and 7%, respectively, with increasing concentrate proportion (p<0.001 and p<0.01, respectively). Both feed and energy conversion rates were poorer with Hf than with Ch bulls (13.5 vs. 11.3 kg DM kg^{-1} carcass gain and 155 vs. 131 MJ kg^{-1} carcass gain, respectively, p<0.001). The RSM supplementation had no effect on feed or energy conversion, but both variables tended to be 5% poorer on RSM-diets than on RSM+ diets (p<0.1).

Carcass characteristics and valuable cuts

There were no interactions for carcass weight or dressing proportion between breed, concentrate level and RSM supplementation. The mean carcass weights of the Hf and Ch bulls were 386 and 426 kg, respectively, and close to the pre-planned carcass weight (Table 3). The carcass weight of the M bulls was 5% higher than that of the L bulls (396 vs. 416 kg, p<0.01). The RSM supplementation had no effect on carcass weight. The dressing proportion of the Ch bulls was 6 % higher than that of the Hf bulls (531 vs. 562 g kg^{-1}, p<0.001). The dressing proportion of the M bulls was 1% higher than that of the L bulls (543 vs. 550 g kg^{-1}, p<0.05), but the RSM supplementation had no effect on dressing proportion.

The carcass conformation score of the Ch bulls was 32% higher than that of the Hf bulls (6.5 vs. 8.6, p<0.001) and the conformation of the M bulls was 17% higher than that of the L bulls (6.9 vs. 8.1, p<0.001). There was also an interaction (p<0.01) between the breed and the concentrate level for carcass conformation. The conformation score of the Ch bulls improved more than that of the Hf bulls as a consequence of increased concentrate level (Table 3). The RSM supplementation had no effect on carcass conformation score. Carcass fat score of the Hf bulls was 55% higher than that of the Ch bulls (4.5 vs. 2.9, p<0.001). The concentrate level had no effect on carcass fat score, but it tended to be 7% higher on M diets than on L diets (3.8 vs. 3.6, p=0.06). The RSM supplementation had no effect on carcass fat score, and there were no interactions for carcass fat score between breed, concentrate level and RSM supplementation (Table 3).

Table 3. Effects of breed (B), concentrate level (C) and rapeseed meal supplementation (RSM) on daily dry matter (DM) intake, apparent diet digestibility, growth performance and carcass characteristics of growing bulls.

Breed (B) [a]	HF				CH				SEM[b]							
Concentrate level (C) [c]	L (200)		M (500)		L (200)		M (500)			*p*-value						
RSM supplementation (RSM)	-	+	-	+	-	+	-	+		B	C	RSM	B×C	B×RSM	C×RSM	B×C×RSM
Number of animals	11	12	12	11	11	12	11	10								
Duration of the experiment, d	356	355	310	327	336	342	306	299	19.2	0.03	0.001	0.64	0.99	0.75	0.26	0.75
Intake																
DM intake, kg d^{-1}	8.91	9.07	9.31	9.76	8.94	8.61	10.04	10.01	0.258	0.21	<0.001	0.59	0.03	0.13	0.76	0.80
DM intake, g kg^{-1} $W^{0.75}$	82.8	83.6	86.7	88.9	81.3	78.1	88.8	87.4	1.88	0.16	<0.001	0.88	0.11	0.11	0.56	0.97
Metabolizable energy, MJ d^{-1}	101	102	111	117	101	96	120	119	3.1	0.36	<0.001	0.77	0.02	0.12	0.78	0.66
Crude protein, g d^{-1}	1292	1411	1282	1447	1289	1340	1390	1491	40.8	0.34	0.002	<0.001	0.01	0.13	0.95	0.78
AAT [d], g d^{-1}	775	811	856	923	772	765	925	945	24.0	0.40	<0.001	0.04	0.02	0.13	0.71	0.76
PBV [e], g d^{-1}	64	121	-74	-16	62	120	-73	-9	8.6	0.01	<0.001	<0.001	0.08	0.53	<0.001	0.17
Neutral detergent fibre, g d^{-1}	4135	4256	3453	3618	4238	4104	3732	3736	111.0	0.06	<0.001	0.45	0.10	0.13	0.84	0.89
Digestibility coefficients																
dry matter	0.75	0.75	0.79	0.78	0.76	0.76	0.77	0.79	0.006	0.72	<0.001	0.87	0.05	0.22	0.51	0.04
organic matter	0.77	0.77	0.81	0.80	0.78	0.77	0.79	0.80	0.006	0.80	<0.001	0.91	0.06	0.17	0.42	0.03
crude protein	0.72	0.77	0.74	0.79	0.73	0.77	0.73	0.80	0.010	0.47	0.005	<0.001	0.29	0.44	0.39	0.26
neutral detergent fibre	0.72	0.72	0.71	0.70	0.73	0.72	0.68	0.70	0.007	0.09	<0.001	0.81	0.13	0.87	0.34	0.03
Initial live weight, kg	311	311	308	305	327	318	325	331	18.0	0.01	0.74	0.84	0.50	0.91	0.30	0.91
Final live weight, kg	712	726	716	749	730	741	769	784	18.9	0.02	0.03	0.12	0.24	0.67	0.61	0.75
Live weight gain, g d^{-1}	1102	1193	1337	1383	1213	1256	1499	1543	55.1	<0.001	<0.001	0.08	0.26	0.68	0.67	0.75
Carcass gain, g d^{-1}	605	649	746	775	728	768	934	939	30.3	<0.001	<0.001	0.08	0.13	0.69	0.45	0.76
Feed conversion																
Kg DM kg^{-1} carcass gain	15.0	14.0	12.5	12.6	12.5	11.3	10.7	10.7	0.48	<0.001	<0.001	0.07	0.16	0.74	0.13	0.91
MJ kg^{-1} carcass gain	171	158	149	151	140	126	128	128	5.8	<0.001	0.004	0.06	0.17	0.76	0.15	0.80
Carcass characteristics																
Carcass weight, kg	375	383	382	402	406	418	438	439	11.3	<0.001	0.008	0.12	0.33	0.62	0.76	0.46
Dressing proportion, g kg^{-1}	526	528	533	538	555	563	569	560	5.0	<0.001	0.02	0.57	0.57	0.71	0.55	0.18
Conformation score [f]	6.3	6.1	6.7	6.7	7.5	7.8	9.8	9.2	0.33	<0.001	<0.001	0.63	0.002	0.85	0.28	0.18
Fat score [g]	4.5	4.5	4.5	4.7	2.7	2.7	3.0	3.2	0.22	<0.001	0.06	0.45	0.34	0.99	0.56	0.84

[a] HF = Hereford; CH = Charolais. [b] Standard error of mean (for n=10). [c] L = low concentrate proportion (200 g kg^{-1} DM); M = medium concentrate proportion (500 g kg^{-1} DM). [d] Amino acids absorbed from small intestine. [e] Protein balance in the rumen. [f] Conformation: (1 = poorest, 15 = excellent). [g] Fat cover: (1 = leanest, 5 = fattest).

Table 4. Effects of breed (B), concentrate level (C) and rapeseed meal supplementation (RSM) on valuable cuts (half carcass) of growing bulls.

Breed (B) [a]	HF				CH				SEM[b]							
Concentrate level (C) [c]	L (200)		M (500)		L (200)		M (500)			*p*-value						
RSM supplementation (RSM)	-	+	-	+	-	+	-	+		B	C	RSM	B×C	B×RSM	C×RSM	B×C×RSM
Number of animals	7	8	8	7	7	8	8	7								
Valuable cuts																
Tenderloin, kg	2.2	2.1	2.2	2.2	2.6	2.7	2.7	2.8	0.11	<0.001	0.63	0.88	0.76	0.41	0.99	0.56
From yield, %	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.3	0.05	<0.001	0.73	0.31	0.17	0.76	0.34	0.44
Loin, kg	5.1	5.3	5.5	5.7	6.1	6.2	6.6	6.7	0.24	<0.001	0.004	0.44	0.74	0.84	0.70	0.98
From yield, %	2.6	2.8	2.8	3.0	2.8	2.9	3.1	2.9	0.10	0.07	0.008	0.18	0.58	0.07	0.34	0.33
Entrecote, kg	3.0	3.1	3.1	3.0	3.2	3.5	3.5	3.7	0.13	<0.001	0.12	0.11	0.16	0.21	0.30	0.93
From yield, %	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.7	0.06	0.04	0.03	0.11	0.24	0.41	0.63	0.30
Outside round, kg	10.3	10.5	10.5	10.8	12.2	12.9	14.1	13.6	0.44	<0.001	0.01	0.46	0.10	0.92	0.32	0.27
From yield, %	5.3	5.5	5.7	5.5	5.8	5.9	6.3	6.2	0.21	<0.001	0.03	0.89	0.46	0.88	0.16	0.83
Inside round, kg	5.8	5.7	6.0	6.0	7.0	7.4	7.9	7.4	0.26	<0.001	0.06	0.91	0.65	0.70	0.28	0.18
From yield, %	3.0	3.1	3.1	3.1	3.3	3.3	3.6	3.4	0.14	0.002	0.17	0.94	0.37	0.41	0.33	0.73
Corner round, kg	5.8	5.7	5.9	6.0	7.1	7.3	7.5	7.6	0.24	<0.001	0.09	0.51	0.70	0.65	0.83	0.55
From yield, %	3.0	3.1	3.2	3.1	3.3	3.3	3.3	3.5	0.13	<0.001	0.10	0.73	0.75	0.67	0.85	0.18
Roast beef, kg	2.8	2.8	2.9	2.7	3.7	3.9	3.9	3.7	0.16	<0.001	0.88	0.72	0.77	0.53	0.18	0.50
From yield, %	1.4	1.5	1.5	1.5	1.6	1.7	1.8	1.6	0.10	0.002	0.67	0.62	0.94	0.80	0.23	0.41
Subcutaneous fat, kg	26.6	21.6	21.2	20.7	16.2	16.8	14.7	15.4	2.33	<0.001	0.09	0.38	0.58	0.17	0.30	0.41
From yield, %	13.1	11.0	10.6	10.2	8.3	8.4	6.7	7.0	1.17	<0.001	0.02	0.40	0.92	0.23	0.38	0.55
Bones, kg	36.8	36.1	36.8	35.4	38.1	38.1	40.7	41.4	1.54	<0.001	0.11	0.63	0.06	0.47	0.90	0.66
From yield, %	18.1	18.5	18.0	17.3	19.5	19.0	18.8	19.0	0.55	0.002	0.16	0.63	0.65	0.89	0.60	0.15

[a] HF = Hereford; CH = Charolais. [b] Standard error of mean (for n=7). [c] L = low concentrate proportion (200 g kg^{-1} DM); M = medium concentrate proportion (500 g kg^{-1} DM).

There were no significant interactions for carcass cuts between breed, concentrate level and RSM supplementation (Table 4). Breed had a clear effect on the amount (kg) and yield (%) of valuable cuts. The yields of tenderloin (p<0.001), loin (p=0.07) and entrecote (p<0.05) were 13, 4 and 5% higher with Ch than with Hf bulls, respectively. In addition, the yields of outside round (p<0.001), inside round (p<0.01), corner round (p<0.001) and roast beef (p<0.01) were 9, 10, 10 and 14% higher with Ch than with Hf bulls, respectively. The yield of subcutaneous fat was 49% higher (p<0.001) from the carcasses of the Hf bulls than those of the Ch bulls. On the contrary, the yield of bones was 6% higher (p<0.01) from the carcasses of the Ch bulls than those of the Hf bulls. Concentrate level affected the yields of loin, entrecote, outside round and subcutaneous fat (Table 4). The yields of loin (p<0.01), entrecote (p<0.05) and outside round (p<0.05) were 6, 5 and 5% higher with M bulls than with L bulls, respectively. The yield of subcutaneous fat was 18% higher (p<0.05) from the carcasses of the L bulls than from those of the M bulls. The RSM supplementation had no effect on the amount and yield of valuable cuts.

Meat evaluation

The treatments had no effects on the pH of the carcasses, but significant breed × concentrate level × RSM supplementation three-way interaction was observed (Table 5). The loin sample of the Ch bulls had higher moisture (739 vs. 726 g kg^{-1}, p<0.001) and protein (213 vs. 210 g kg^{-1}, p<0.05) and lower fat (35 vs. 51 g kg^{-1}, p<0.001) contents than that of the Hf bulls. Concentrate level and RSM supplementation had no effects on the chemical composition of loin, and there were no significant interactions between breed, concentrate level and RSM supplementation. Breed affected the marbling score of loin and entrecote (Table 5). The loin (p<0.001) and entrecote (p<0.01) of the Hf bulls had 39 and 44% higher marbling scores than those of the Ch bulls, respectively. Concentrate level and RSM supplementation had no effects on the marbling score of the loin or entrecote. Interactions for marbling scores between breed, concentrate level and RSM supplementation were not observed.

There were no interactions for shear force value, drip loss, colour or sensory characteristics between breed, concentrate level and RSM supplementation (Table 5). The treatments had no effects on the drip loss, but the shear force value of the Ch bulls was 13% higher than that of the Hf bulls (9.9 vs. 8.8 kg cm^{-1}, p<0.05). Concentrate level and RSM supplementation had no effects on the shear force value. The muscle lightness (L value) of the Ch bulls was 8% higher than that of the Hf bulls (p<0.001), but there were not differences in redness (a value) or yellowness (b value) between breeds. In addition, the muscle lightness was 3% higher with M bulls than with L bulls, but concentrate level did not affect the muscle redness or yellowness. The RSM supplementation had no effects on any of the measured meat colour parameters. Treatments had no effects on the sensory characteristics (tenderness, juiciness, beef flavour) of the loin, but there was a tendency (p=0.08) for tenderness to be 6% better for the meat of the Hf bulls than that of the Ch bulls.

The *n*-6/*n*-3 fatty acid ratio of the *longissimus* muscle (LM) of the Ch bulls was 20% higher than the corresponding value for the Hf bulls (p<0.01) (Table 6). In addition, the LM of the Ch bulls contained a higher proportion of polyunsaturated fatty acids (PUFA) compared to that of the Hf bulls (p<0.001). On the contrary, the LM of the Hf bulls contained a higher proportion of monounsaturated fatty acids (MUFA) compared to that of the Ch bulls (p<0.01). Breed had no effect on the proportion of saturated fatty acids (SFA). The LM of the Hf bulls had a higher proportion of 10:0 (p<0.05), 18:1 *cis*-9 (p<0.001) and 20:1 *cis*-11 (p<0.05) fatty acids compared to that of the Ch bulls. On the contrary, the LM of the Ch bulls contained a higher proportion of 15:0 (p<0.01), 16:0 (p<0.05), 16:1 *cis*-9 (p<0.001), 18:1 *cis*-11 (p<0.001), 18:2 *cis*-9,*cis*-12 (p<0.001), 18:3 *cis*-9,*cis*-12,*cis*-15 (p<0.001), 18:3 *cis*-6,*cis*-9,*cis*-12 (p<0.001) and 20:3 *cis*-8, *cis*-11, *cis*-14 (p<0.01) fatty acids compared to that of the Hf bulls.

The *n*-6/*n*-3 fatty acid ratio of the LM increased 59% with higher concentrate level (p<0.001) and the LM of the M bulls also tended (p=0.05) to contain a 5% higher proportion of MUFA compared to that of the L bulls (Table 6). On the contrary, the LM of the L bulls tended (p=0.06) to have a 4% higher proportion of SFA compared to that of the M bulls. Concentrate level had no effect on the proportion of PUFA. The increasing concentrate level decreased the relative proportion of 15:0 (p<0.001), 17:0 (p<0.001), 18:1 *cis*-11 (p<0.05) and 18:3 *cis*-9,*cis*-12,*cis*-15 (p<0.001) fatty acids of the LM and increased the relative proportion of 18:1 *cis*-9 (p<0.05) and 18:2 *cis*-9,*cis*-12 (p<0.01) fatty acids of the LM. In addition, the LM of the M bulls tended (p=0.09) to have a higher proportion of 10:0 fatty acid compared to that of the L bulls (Table 6).

Table 5. Effects of breed (B), concentrate level (C) and rapeseed meal supplementation (RSM) on meat quality of growing bulls.

Breed (B) [a]	HF				CH				SEM[b]							
Concentrate level (C) [c]	L (200)		M (500)		L (200)		M (500)			*p*-value						
RSM supplementation (RSM)	-	+	-	+	-	+	-	+		B	C	RSM	B×C	B×RSM	C×RSM	B×C×RSM
Number of animals	7	8	8	7	7	8	8	7								
pH	5.51	5.57	5.55	5.51	5.55	5.53	5.55	5.55	0.022	0.67	0.91	0.97	0.30	0.45	0.19	0.03
Chemical composition, g kg^{-1}																
Moisture	722	734	720	731	744	742	735	734	6.1	<0.001	0.11	0.16	0.59	0.09	0.86	0.90
Protein	210	211	209	210	211	213	213	214	2.0	0.04	0.89	0.44	0.26	0.99	0.90	0.90
Fat	54	42	58	46	32	32	39	39	6.9	<0.001	0.14	0.12	0.89	0.22	0.93	0.99
Shear force value, kg cm^{-1}	9.3	8.9	8.7	8.3	9.7	10.4	9.4	10.3	0.77	0.01	0.37	0.73	0.77	0.21	0.91	0.89
Drip loss, %	0.80	0.73	1.22	1.03	1.63	0.76	1.16	1.68	0.358	0.16	0.13	0.36	0.82	0.68	0.23	0.10
Colour at 14 d																
"L" (lightness)	37.0	36.4	37.9	37.9	38.8	39.8	39.8	42.2	0.77	<0.001	0.007	0.25	0.76	0.08	0.38	0.61
"a" (redness)	24.6	24.0	24.5	24.2	25.2	23.5	24.7	22.9	1.12	0.79	0.95	0.12	0.60	0.29	0.88	0.89
"b" (yellowness)	7.3	6.5	6.7	6.7	7.5	7.2	7.2	6.7	0.75	0.36	0.74	0.40	0.72	0.86	0.92	0.65
Sensory analysis [d]																
Tenderness	6.0	5.9	5.9	5.6	5.5	5.4	5.8	5.7	0.28	0.08	0.74	0.40	0.19	0.95	0.57	0.83
Juiciness	5.8	5.8	5.4	5.3	5.4	5.6	5.6	5.4	0.23	0.56	0.11	0.93	0.09	0.93	0.37	0.78
Beef flavour	5.5	5.5	5.7	5.5	5.6	5.6	5.4	5.5	0.19	0.81	0.97	0.81	0.50	0.64	0.74	0.65
Marbling score [e]																
Loin	1.97	1.78	2.05	1.58	1.17	1.19	1.52	1.43	0.218	<0.001	0.44	0.22	0.22	0.26	0.58	0.78
Entrecote	1.74	1.38	1.43	1.25	0.83	0.91	1.01	1.21	0.238	0.003	0.92	0.62	0.14	0.16	0.53	0.97

[a] HF = Hereford; CH = Charolais. [b] Standard error of mean (for n=7). [c] L = low concentrate proportion (200 g kg^{-1} DM); M = medium concentrate proportion (500 g kg^{-1} DM). [d] Sensory analysis: scale from 1 to 7. Tenderness: 1=very tough, 7=very tender. Juiciness: 1=very dry, 7=very juicy. Beef flavour: 1=very non beef like, 7=very beef like.
[e] Marbling score: scale from 0 to 5 (0=devoid, 5=abundant).

Table 6. Effects of breed (B), concentrate level (C), and rapeseed meal supplementation (RSM) on fatty acid profile (% of total fatty acids) of the *Longissimus* muscle of growing bulls.

Breed (B) [a]	HF				CH				SEM[b]							
Concentrate level (C) [c]	L (200)		M (500)		L (200)		M (500)			*p*-value						
RSM supplementation (RSM)	-	+	-	+	-	+	-	+		B	C	RSM	B×C	B×RSM	C×RSM	B×C×RSM
Number of animals	7	8	8	7	7	8	8	7								
8:0	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.004	0.29	0.45	0.06	0.85	0.25	0.40	0.87
10:0	0.03	0.02	0.03	0.04	0.03	0.01	0.02	0.02	0.009	0.01	0.09	0.04	0.22	0.11	0.001	0.96
12:0	0.06	0.03	0.06	0.05	0.06	0.06	0.07	0.05	0.018	0.38	0.55	0.23	0.43	0.79	0.91	0.50
14:0	3.05	2.66	2.96	2.75	3.27	2.85	2.87	2.90	0.189	0.14	0.47	0.02	0.46	0.58	0.25	0.50
14:1 *cis*-9	0.59	0.43	0.46	0.56	0.56	0.49	0.59	0.49	0.070	0.46	0.85	0.15	0.89	0.82	0.16	0.10
15:0	0.42	0.39	0.36	0.35	0.54	0.53	0.34	0.37	0.047	0.003	<0.001	0.76	0.03	0.49	0.66	0.78
16:0	29.94	28.09	29.02	28.19	31.03	28.99	30.16	28.80	0.697	0.02	0.24	<0.001	0.90	0.76	0.35	0.90
16:1 *cis*-9	3.71	3.13	3.53	3.45	3.98	3.87	4.12	3.73	0.208	<0.001	0.89	0.02	0.76	0.29	0.80	0.14
17:0	0.98	1.04	0.93	0.92	1.05	1.06	0.84	0.90	0.059	0.89	<0.001	0.41	0.19	0.95	0.81	0.38
17:1 *cis*-10	0.83	0.78	0.73	0.59	0.76	0.67	0.71	0.74	0.081	0.55	0.14	0.16	0.10	0.72	0.96	0.28
18:0	17.35	19.42	18.53	17.49	17.30	18.45	16.23	18.02	0.903	0.14	0.33	0.07	0.76	0.57	0.20	0.09
18:1 *cis*-9	37.62	38.84	37.77	40.13	34.77	34.04	36.87	37.55	1.129	<0.001	0.02	0.16	0.13	0.17	0.34	0.93
18:1 *cis*-11	2.03	1.90	1.96	1.95	2.34	2.84	2.16	2.01	0.164	<0.001	0.01	0.49	0.01	0.05	0.12	0.10
18:2 *cis*-9, *cis*-12	1.33	1.29	1.64	1.59	1.53	2.16	2.24	2.02	0.158	<0.001	0.006	0.36	0.89	0.07	0.04	0.05
18:3 *cis*-6, *cis*-9, *cis-12*	0.44	0.41	0.55	0.46	0.65	1.12	0.94	0.67	0.111	<0.001	0.90	0.48	0.21	0.06	0.004	0.03
18:3 *cis*-9, *cis*-12, *cis*-15	0.66	0.64	0.52	0.44	0.80	0.95	0.59	0.56	0.075	<0.001	<0.001	0.93	0.11	0.23	0.31	0.37
18:2 *cis*-9, *trans*-11 CLA	0.27	0.21	0.18	0.20	0.27	0.31	0.23	0.23	0.057	0.17	0.12	0.96	0.90	0.52	0.65	0.42
20:0	0.07	0.12	0.10	0.15	0.10	0.14	0.06	0.13	0.046	0.73	0.66	0.11	0.31	0.79	0.57	0.92
20:1 *cis*-11	0.08	0.20	0.14	0.15	0.09	0.04	0.10	0.19	0.045	0.05	0.11	0.13	0.17	0.20	0.77	0.03
20:2 *cis*-11, *cis*-14	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.015	0.26	0.39	0.30	0.35	0.26	0.39	0.33
20:3 *cis*-11, *cis*-14, *cis*-17	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.00	0.018	0.13	0.25	0.74	0.20	0.76	0.82	0.79
20:3 *cis*-8, *cis*-11, *cis*-14	0.04	0.00	0.09	0.13	0.38	0.19	0.25	0.18	0.106	0.006	0.75	0.27	0.24	0.26	0.40	0.95
22:0	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.028	0.38	0.27	0.30	0.35	0.38	0.27	0.33
22:2 *cis*-13, *cis*-16	0.50	0.42	0.32	0.43	0.31	0.69	0.57	0.37	0.128	0.46	0.66	0.75	0.88	0.82	0.98	0.003
SFA [d]	51.94	51.76	52.05	50.02	53.40	55.34	50.59	51.15	1.772	0.17	0.06	0.99	0.21	0.25	0.41	0.90
MUFA [e]	44.82	45.27	44.60	46.75	42.49	39.09	44.55	44.75	1.692	0.008	0.05	0.96	0.11	0.15	0.23	0.62
PUFA [f]	3.24	2.97	3.34	3.24	4.11	5.58	4.87	4.10	0.507	<0.001	0.92	0.82	0.29	0.34	0.22	0.04
n6/n3	2.86	2.77	4.63	4.74	3.26	4.05	5.73	5.18	0.557	0.004	<0.001	0.61	0.91	0.44	0.25	0.31

[a] HF = Hereford; CH = Charolais. [b] Standard error of mean (for n=7). [c] L = low concentrate proportion (200 g kg^{-1} DM); M = medium concentrate proportion (500 g kg^{-1} DM).
[d] Saturated fatty acids.
[e] Monounsaturated fatty acids.
[f] Polyunsaturated fatty acids.

There were no effects of RSM supplementation on the *n*-6/*n*-3 fatty acid ratio of the LM or on the proportion of SFA, MUFA or PUFA. However, RSM supplementation decreased the relative proportion of 10:0 ($p<0.05$), 14:0 ($p<0.05$), 16:0 ($p<0.001$) and 16:1 *cis*-9 ($p<0.05$) fatty acids of the LM. There were also interactions ($p<0.05$) between breed and concentrate level for the relative proportion of 15:0 and 18:1 *cis*-11 fatty acids, and between the breed and RSM supplementation for the relative proportion of 18:1 *cis*-11 fatty acid (Table 6). In addition, there were interactions between concentrate level and RSM supplementation for the relative proportion of 10:0, 18:2 *cis*-9,*cis*-12 and 18:3 *cis*-6,*cis*-9,*cis*-12 fatty acids. Significant breed × concentrate level × RSM supplementation three-way interactions were observed for the relative proportion of 18:2 *cis*-9,*cis*-12, 18:3 *cis*-6,*cis*-9,*cis*-12, 20:1 *cis*-11 and 22:2 *cis*-13,*cis*-16 fatty acids and for the proportion of PUFA (Table 6).

Discussion

Animal performance

The increased apparent digestibility of DM (DMD) and OM (OMD) of grass silage-based diets due to increasing concentrate feed level has been well documented (Huuskonen et al. 2007, Keady et al. 2007, 2008). The substitution of silage with barley improved the digestibility, because the digestibility of barley is generally higher than that of grass silage (MTT 2012). The reduction in fibre digestibility due to increased concentrate level has been reported previously Steen et al. (2002), Huuskonen et al. (2007) and Keady et al. (2007, 2008). The negative associative effect is attributed to a depression in fibre digestibility in the rumen and in the total digestive tract from inclusion of rapidly fermentable carbohydrates such as barley-based (starch) concentrate (Huhtanen and Jaakkola 1993) and sucrose (Khalili and Huhtanen 1991) in grass silage-based diets. In accordance with Huuskonen et al. (2007, 2008b) and Huuskonen (2009b), the apparent CP digestibility increased with protein supplementation. Some of the increased apparent digestibility of the CP in the RSM supplemented diets may have reflected the better digestibility of RSM protein. Most of this increase was, probably, only apparent, related to the decreased proportion of faecal metabolic nitrogen recovered in faeces when the CP content increased (Minson 1982). Similarly, as reported by Huuskonen et al. (2007) and Huuskonen (2009b), RSM supplementation had no effect on diet apparent DMD or OMD when barley grain was partly replaced by RSM. Most of the experiments in which protein supplementation resulted in positive effects on fibre digestion, have been conducted with poor quality roughages (Huuskonen 2009a).

The concentrate proportion had a positive effect on the total DMI which is in accordance with results of beef steers in grass silage-based diets (Caplis et al. 2005, Keane et al. 2006). The substitution rate (SR, decrease in silage DMI per kg increase of concentrate DMI) in the current experiment was 0.81 and 0.60 for Hf and Ch bulls, respectively. These results are in line with grass silage-based feedings reported by Keane (2010) with crossbred steers (SR 0.82), Manninen et al. (2010) with Hf bulls (SR 0.71 and 0.53 for farm-made concentrate mixture and commercial compound, respectively) and Randby et al. (2010) with dairy bulls (SR 0.75). McNamee et al. (2001) reported that concentrate feed level and silage feed value are major factors affecting the concentrate substitution rate. For example, Keady and Kilpatrick (2006) (beef-breed bulls) and Steen et al. (2002) (beef-breed steers), using high-feed value grass silages, reported substitution rates of 0.91 and up to 1.00, respectively. The concentrate protein concentration did not affect DMI, which was consistent with the results observed with heavy dairy bulls (Huuskonen et al. 2007, Huuskonen 2009b), finishing Hereford bulls (Manninen et al. 2011) or suckled continental-cross bulls (Drennan et al. 1994) with grass silage-based diets.

The higher growth capacity of the Charolais breed compared to the Hereford breed has been demonstrated in numerous studies (e.g. Gregory et al. 1994, Aass and Vangen 1998, Bartoň et al. 2006). In the present experiment, the observed increase in LWG was 75 and 91 g d^{-1} per 1 kg increase in concentrate DMI for Hf and Ch bulls, respectively. These outcomes are consistent with grass silage feeding experiments reported by Martinsson (1990) with dairy bulls (84 g d^{-1}) and Manninen et al. (2010) with Hf bulls (85 and 90 g d^{-1}, for farm-made concentrate mixture and commercial compound, respectively), but sometimes responses have been even smaller (dairy bulls, 27 g d^{-1}) (Huuskonen et al. 2007). The improved growth rate in the present experiment was probably due to improved diet digestibility and increased DM and energy intakes with increasing concentrate proportion.

In the present experiment, the growth rate of the bulls tended to be slightly lower on RSM− diets than on RSM+ diets, which disagrees with the findings by Huuskonen et al. (2007, 2008b) and Huuskonen (2009b, 2011) with dairy bulls. The observed response in LWG due to RSM supplementation was slightly higher with lower concentrate proportion (67 vs. 45 g d^{-1} for L and M feedings, respectively). This is in line with Huuskonen (2009a) who concluded that the responses to protein supplements seem to be related also to the level of concentrate supplement, greater effects being observed with small amounts of concentrates. Hagemeister et al. (1980) reported a tendency towards lower rumen protein synthesis with rations containing very low (0–20%) or very high (70–100 %) proportions of concentrate, and according to Aronen (1992), a medium level of concentrates together with well preserved grass silage may sustain efficient microbial protein production. Therefore, it is likely that a greater response to protein supplementation is to be expected when small rather than large amounts of concentrates are fed to growing cattle on grass silage-based feeding.

In general, the responses to protein supplements are also related to the quality of grass silage used. There is evidence that growing cattle are likely to respond to supplementary protein in barley-based concentrates when the digestibility of the grass silage is moderate to low (Huuskonen 2009a). In addition, results with grass silage are dependent on the quality of silage that may vary considerably with the ensiling technique. With poorly preserved silage the response in animal performance to protein supplementation is greater than with well-preserved silage (Hussein and Jordan 1991). There are also differences between extensively and restrictively fermented silages, which both may be well-preserved. Jaakkola et al. (1990) reported that the gain response of growing cattle to fishmeal was greater when enzyme solution (cellulose–glucose oxidase) was used as a silage additive instead of formic acid. Furthermore, Jaakkola et al. (2006) observed that restriction of silage fermentation by formic acid is positively related to the synthesis of microbial protein in the rumen. In the present experiment the fermentation quality of the silages was good and the silages were restrictively fermented with high residual WSC concentration and low lactic acid concentration. Possibly, the responses to protein supplementation may have been greater with untreated and/or poorly preserved silage.

Carcass characteristics and valuable cuts

The superiority of the Ch bulls for the dressing proportion and carcass conformation corresponded to the results reported by Polách et al. (2004) and Bartoň et al. (2006). The lower dressing proportion and conformation score of the Hf bulls in the present experiment can also be explained partly by their lower average slaughter weight compared to Ch bulls because it is established that these traits increased with increasing slaughter weight (Kempster et al. 1988). However, according to Lawrence et al. (2012) the body composition of beef breeds is not only dependent on carcass weight. For example, when early maturing Hf and late maturing Blonde d'Aquitaine breeds were compared, the relative fatness of both breeds remained quite similar at different weights. Both breeds increased in fatness as the carcass weight increased but the differential remained quite constant (Lawrence et al. 2012). The different breed bulls are in different stages of their growth path from the beginning of the growing till the end of finishing. The mature weight of the Ch bulls is larger than the Hf bulls but also the tissue composition is different (Alberti et al. 2008). In this regard the Ch bulls will not reach the similar body composition (fat vs. lean) as adult animals such as the Hf bulls. It is justifiable to suppose that the apparently higher carcass efficiency of the Ch bulls compared to the Hf bulls observed in the present experiment was real, and the differences were not only an effect of differences in biological maturity.

The increasing effect of concentrate level on dressing proportion agrees with previous reports (Caplis et al. 2005, Keane et al. 2006). In the present experiment, increasing concentrate proportion also improved the carcass conformation, consistent with Keane and Fallon (2001) and Caplis et al. (2005), but contrary to Huuskonen et al. (2007), Manninen et al. (2010) and Randby et al. (2010). Increasing the concentrate level has usually increased the carcass fat score (Patterson et al. 2000, Keane et al. 2006) as in the present experiment. Also higher slaughter weights with increasing concentrate level probably explained the increased fat score, because measures of fatness generally increase with higher carcass weight (Keane and Allen 1998). In accordance with many earlier studies (Huuskonen et al. 2007, 2008b, Manninen et al. 2010, Huuskonen 2009, 2011), there were no effects of protein supplementation on the dressing proportion, carcass conformation score or carcass fat score.

Manninen et al. (2011) reported a similar carcass share of valuable cuts in Hf bulls to those obtained in the present paper. A number of studies have confirmed a higher share of the most valuable cuts in the carcasses of Ch bulls compared to Hf bulls (e.g. Bartoň et al. 2006, Kaminiecki et al. 2009). Also Kempster et al. (1982) reported a lower saleable meat proportion from carcasses of Hf-sired steers than from carcasses of Ch steers compared at 16 months of age. Similarly to our findings, Bartoň et al. (2006) observed that Hf bulls had a lower percentage of bones compared to Ch bulls. The effects of concentrate proportions on the yields of valuable cuts were quite small and there were only few differences between the different concentrate levels which agree with the findings by Patterson et al. (2000), Caplis et al. (2005) and Keane et al. (2006). Patterson et al. (2000) speculated that the absence of any effect of concentrate proportion on the content of saleable meat in the carcass was considered to reflect the high growth potential of the animals (Blonde d'Aquitaine and Ch bulls). Caplis et al. (2005) observed that bone proportion decreased in growing beef steers with increasing concentrate level which disagrees with our observation. In accordance with the present study, Manninen et al. (2011) reported that the protein supplementation had no effect on the amount and yield of valuable cuts in beef bulls.

Meat quality measurements

The meat colour differences between the breeds corresponded to those reported by Aass and Vangen (1998) who reported meat from Ch to be lighter than meat from Hf. Some studies associated increased lightness with reduced pigment content in the meat of Ch, which suggests the presence of breed differences in relative muscle fibre proportion. Such physiological changes may be related to high genetic growth capacity and increased muscularity (Ashmore and Vigneron 1988). In accordance with Bureš et al. (2006), the meat samples from Hf bulls had higher DM and lipid contents and a lower protein content than the samples from Ch bulls. These results indicate that the increase in lipid concentrations was associated with the increased DM content and the decreased protein content, which is in accordance with the findings by Van Koevering et al. (1995). Similarly to the present results, greater intramuscular fat deposition and lower moisture in Hf steers compared with Ch steers were reported by Gregory et al. (1994).

In agreement with our findings, Bureš et al. (2006) reported no significant effects on sensory characteristics (juiciness, beef flavour) between Hf and Ch bulls. In our study, however, there was a tendency for the tenderness to be 6% better in the meat of the Hf bulls than that of the Ch bulls. Similarly, poorer tenderness was achieved by large, late maturing Ch steers than by small, early maturing, and fatter Aberdeen Angus steers (Sinclair et al. 2001). The superiority of Hf in tenderness and shear force has been related to a higher marbling level. Several authors (e.g. Gregory et al. 1994, Wheeler et al. 1996) have reported a favourable relationship between intramuscular fat content and shear force/tenderness scores. Aass and Vangen (1998) concluded that a superiority of Aberdeen Angus in intramuscular fat content of the meat has been demonstrated in many studies, and Hf was generally ranked similar or somewhat lower than Angus for this trait, while Ch had the lowest degree of marbling in the meat. This statement agrees with our finding that the loin and entrecote of the Hf bulls had a clearly higher marbling score than those of the Ch bulls. In the present study, the bulls were slaughtered at high CW and high shear force values obtained correspond with tough meat. It is suggested that the taste of beef will strengthen when animals get older and heavier, but meat will become also tougher due to the strengthening of collagen structure (Lawrie & Ledward, 2006). Therefore, longer ageing period would be necessary in meat from animals slaughtered at high LW.

In general, the feeding treatments had no important effects on meat quality characteristics of the *Longissimus* muscle. These results are broadly in agreement with those reported by Keady et al. (2007, 2008) that concentrate level has no remarkable effect on meat quality of finishing cattle. It is well established that muscle colour is generally darker in forage-fed than in concentrate-fed animals (e.g. Caplis et al. 2005). However, in the present study the muscle lightness (L value) was higher for the M bulls than for the L bulls and the explanation for this effect is not clear. In accordance with our results, Caplis et al. (2005) reported no effects on muscle redness (a value) and yellowness (b value) between concentrate proportions 310 and 550 g kg^{-1} DM. In agreement with the present study, Manninen et al. (2011) reported that protein supplementation had no effect on the shear force value, pH or sensory characteristics in beef bulls.

The present results suggest that Hf bulls produced healthier meat with a lower *n*-6/*n*-3 fatty acid ratio and higher MUFA concentration compared to Ch bulls. Breed differences and associated effects of maturity or growth potential on the subcutaneous or intramuscular fatty acid composition of beef are extensively discussed in the review by de Smet et al. (2004). It is possible that the differences in carcass fat score between breeds in the present experiment (4.5 vs. 2.9 for Hf and Ch bulls, respectively) affected also the differences in the fatty acid composition of the *longissimus* muscle. According to de Smet et al. (2004), carcass fat score affects the fatty acid profile of the meat, and breed differences reported in the literature are often confounded by differences in fatness as in the present experiment. Nevertheless, specific breed differences in the *n*-6/*n*-3 fatty acid ratio and in the levels of longer chain fatty acids that probably could not be attributed to differences in the fat level have also been reported (de Smet et al. 2004), but many of these breed differences are relatively small and are, although often statistically significant, probably of little value from a nutritional viewpoint.

Our results are mainly in accordance with Daley et al. (2010) who concluded that increasing the concentrate level generally increases the *n*-6/*n*-3 fatty acid ratio of the *longissimus* muscle. A healthy diet should consist of roughly one to four times more omega-6 fatty acids than omega-3 fatty acids. The review by Daley et al. (2010) shows significant difference in the *n*-6/*n*-3 fatty acid ratio between grass-fed and grain-fed beef, with an overall average of 1.53 and 7.65 for grass-fed and grain-fed, respectively, for all the studies reviewed. In our study, *n*-6/*n*-3 fatty acid ratios for L and M feedings were 3.16 and 5.03, respectively. Furthermore, Daley et al. (2010) reported that grain-fed beef consistently produces a lower concentration of 18:3 cis-9,cis-12,cis-15 fatty acid and higher concentrations of MUFAs as compared to grass-fed beef, which includes fatty acids such as 18:1 *cis*-9, the primary MUFA in beef. These findings are in line with the present results.

Limitation of present study is that the breed effects are partly confounded with carcass weight because the target for average carcass weight was different for Hf and Ch bulls. However, the targeted carcass weights are nowadays the average weights for slaughtered bulls of these breeds in Finland. Therefore, the present results are valid from a practical point of view.

Conclusions

In conclusion, breed differences in growth performance and carcass traits were observed when the bulls were slaughtered at typical Finnish carcass weights; 380 and 420 kg for Hf and Ch bulls, respectively. The later maturing Ch bulls tended to achieve higher weight gain, produced less fat and had a higher percentage of their meat in high-priced joints compared to the earlier maturing Hf bulls. On the other hand, Ch had a lower degree of marbling in their meat compared to Hf. The growth performance of the bulls increased with increasing concentrate level and increasing the concentrate allowance also improved carcass conformation. However, also higher slaughter weights with increasing concentrate level probably partly explained some differences in carcass traits between the concentrate proportions. In general, rapeseed meal supplementation had limited effects on the performance, carcass traits or meat quality. According to this study, the choice of breed and feeding can affect the composition of the intramuscular fat. The results indicate that Hf bulls produced healthier meat with a lower *n*-6/*n*-3 fatty acid ratio and higher MUFA concentration compared to Ch bulls. In addition increasing the concentrate level increased the *n*-6/*n*-3 fatty acid ratio of the *longissimus* muscle.

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