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Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of *longissimus* muscle in different cattle breeds

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Abstract

The objective of this study was to examine the effects of feeding system and breed on the content of the beneficial *n*-3 polyunsaturated fatty acids and conjugated linoleic acids (CLA) in beef muscle. German Simmental (GS) (n=31) and German Holstein (GH) (n=33) bulls were produced on either an indoor concentrate system or a grass-based system consisting of a period of summer pasture feeding followed by a winter indoor period on grass silage and a concentrate containing linseed. All animals were slaughtered at 620 kg. The grass-based system increased (P<0.05) the percentage of *n*-3 fatty acids in the *longissimus* muscle lipids of bulls (GS 2.22 vs. 0.46%, GH 1.61 vs. 0.34%). The *n*-6 fatty acid proportions were not affected by the feeding system in GS and GH loin muscle. Therefore, the *n*-6/*n*-3 ratio of grass-based GS bulls was 2.0 and of GH was 1.9 in contrast to 8.3 and 6.5 for bulls fed concentrates indoors. The grass-based system increased the percentage of C18:1*trans* fatty acid isomers in both breeds. The percentage of CLA*cis*-9,*trans*-11 (0.87% vs. 0.72% in GS, 0.84% vs. 0.75% in GH) in muscle was significantly higher in animals on the grass-based system.

Keywords: Beef; *n*-3 fatty acids; Sensory traits; CLA; Shelf life

1. Introduction

Meat has often been identified wrongly as having a high fat and saturated fatty acid content. In fact, lean meat is very low in fat (2–3%). Fat, especially animal fat, has been the subject of much interest and debate because of risks of some diseases when consumed in excess. Fat however is not only a concentrated source of energy for the body, the fat in meat provides flavour, aroma and texture. When eaten, fat is also a carrier of the fat-soluble vitamins A, D, E and K and the essential

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fatty acids, and it is important in growth and in the maintenance of many body functions. Today, it is accepted that both the amount and the structure of the fatty acids play a major role in maintaining health. In Germany, it is recommended that people should decrease their intake of saturated fatty acids (10% of the total calories) and *trans* fatty acids (less than 1%) and to increase the intake of unsaturated fatty acids (0.5%) and to decrease the *n*-6/*n*-3 ratio in the diet to levels ≤5:1 (DGE, 2000). In the UK, the recommendation (Department of Health, 1994) is also for saturated fat to be reduced from 15% to 10% of total energy intake whilst increasing the ratio of polyunsaturated to saturated fatty acids (P/S) to above 0.4. Animal experiments and clinical intervention studies indicate that a lower ratio of *n*-6/*n*-3 fatty acids in dietary fat is desirable in reducing the risk of many chronic diseases (Simopoulos, 2001, 2002; Wolfram, 2003). The consumer's interest in the nutritional aspects of health have increased in recent years. There is more interest in animal production practices, such as the nutrient composition of the diet, which can change the fatty acid profile of meat, milk and eggs to make them more attractive for health reasons (Chilliard et al., 2001; Scollan et al., 2001, 2003; Nuernberg et al., 2002; Lorenz et al., 2002; Mir et al., 2003; Raes et al., 2002; Precht et al., 2002; Yang et al., 2003; Stockdale et al., 2003; French et al., 2003; Dewhurst et al., 2003).

Conjugated linoleic acids are presently the subject of intensive research because of their potent anticarcinogenic effects as well as effects on the immune system and lipid metabolism (Kritchevsky, 2000; Banni et al., 2002; Parodi, 2002; see literature collected http://www.wisc.edu/fri/claefs.htm). CLA is a term used to describe positional and geometric isomers of C18:2. Ruminant products are the richest natural source of CLA*cis*-9,*trans*-11, which is the major isomer in meat. This isomer is formed during biohydrogenation in the rumen and by de novo synthesis in different tissues of cattle or sheep from C18:1 *trans*-11. Griinari et al. (2000) demonstrated that CLA*cis*-9,*trans*-11 can be produced by endogenous synthesis from C18:1*trans*-11 by the enzyme Δ^9-desaturase.

Cattle with a high potential for lean beef production are frequently fattened on concentrate diets, which may be unfavourable to the ratio of *n*-6/*n*-3 polyunsaturated fatty acids in meat because the fat in concentrates contains higher levels of C18:2*n*-6. Including forage in the diet of beef cattle should enhance the *n*-3 fatty acid concentrations because forages are a good source of C18:3*n*-3 (Scollan et al., 2001). Changing the diet and fatty acid composition of meat may also affect sensory eating quality and colour and/or lipid stability of the meat during retail display (Vatansever et al., 2000).

The objective of this experiment was to investigate the effects of genotype and feeding system on meat quality, stability, sensory quality and fatty acid composition of *longissimus* muscle, in particular to examine *n*-3 fatty acids and CLA*cis*-9,*trans*-11 in the intramuscular fat in muscle of German Holstein and German Simmental bulls fed different diets.

2. Materials and methods

In total, 64 cattle (5–6 months old) were randomly assigned to two dietary treatments (concentrate vs. grass-based) in the experiment. For indoor housing, the concentrate group consisted of 16 German Simmental (GS) and 17 German Holstein (GH) bulls. They were fed semi ad libitum maize silage, concentrate, hay, straw and a mixture of minerals and vitamins up to 620 kg live weight. The pelleted concentrate for the indoor concentrate group was a mixture of winter barley, molasses and soybean meal (Vollkraft-Mischfutterwerk, Güstrow). The other half of the animals, 15 GS and 16 GH bulls, were kept on pasture during the summer period. During the following winter period and 3 months before finishing, these bulls were kept in a stable and were fed wilted silage, hay, a pelleted concentrate diet and a mixture of minerals and vitamins up to 620 kg. The pelleted concentrate for the pasture group was a mixture of 12% barley and 10% coarsely cracked linseed (Vollkraft Mischfutterwerk, Güstrow). This system is termed a grass-based system. Table 1 shows the chemical composition and the fatty acid profile of the experimental diet components. Duplicate analyses for all estimated nutrients were carried out by the Weende Feed Analysis method (Naumann and Basler, 1993). Determination of crude protein was conducted by

Table 1
Chemical composition and fatty acid composition of the diet

	Straw	Hay	Grass	Maize silage	Wilted silage	Molasses	Concentrate for grass-based	Concentrate for intensive
Chemical composition[a]								
Crude protein	3.7	13.2	24.21	9.63	20.63	10.0	14.78	20.25
Crude fat	1.36	1.94	4.44	3.18	4.32	1.40	3.36	2.45
Crude ash	5.76	6.90	10.56	4.63	12.17	9.91	8.18	6.02
ADF	54.69	36.4	25.75	26.24	26.03	22.14	13.25	12.59
Fatty acid profile[b]								
C16:0	40.29	32.26	19.44	18.07	19.60	28.46	9.76	20.07
C18:0	2.16	2.28	0.94	2.00	0.76	1.01	2.92	3.35
C18:1*cis*-9	3.90	4.96	1.17	20.60	0.91	8.67	13.81	17.13
C18:2*n*-6	19.09	17.00	11.26	52.42	10.87	47.65	25.55	47.99
C18:3*n*-3	19.49	36.5	64.36	4.65	65.50	9.52	45.98	6.12

[a] Values are expressed on a dry matter basis.
[b] Percentage of total fatty acids by weight.

combustion analysis by Dumas using the equipment "elementar macro N" (Elementar Analysensysteme, Hanau, Germany). The crude fat determination was conducted with HCl-hydrolysis according to Kuhla et al. (1983). Acid detergent fibre (ADF) was detected according to Goering and van Soest (1970). The fatty acid profile was analysed by gas chromatography (Nuernberg et al., 2002).

All bulls were slaughtered as they reached 620 kg live weight by captive bolt stunning followed by exsanguination in the abattoir of the Research Institute for the Biology of Farm Animals in Dummerstorf. The carcasses were chilled for 24 h before sampling. The slaughter and dressing procedures were in accordance with EU specifications. *Longissimus* muscle samples for meat quality, sensory analysis, lipid oxidation (TBARS) and fatty acid analysis were taken at the 6th–13th rib of the left carcass side 24 h after slaughter. The pH value and the meat colour of the *longissimus* muscle at 24 h were measured on the left carcass side at the 7th/9th rib using a pH-Star meter (Ingenieurbüro R. Matthäus, Ebenried) and using a Minolta Chroma-meter CR 200 (Minolta Europe GmbH Langenhagen), respectively. One section of *longissimus* muscle (2.54 cm) was conditioned at 2 °C for 12 days, then cooked to 160 °C in an oven for 75 min in an aluminium container. After cooling for 90 min at room temperature, three to four cores were cut from the steaks parallel to the muscle fibre orientation. The shear force (WBSF) was measured with the Texture Analyser Winopal (Ahnbeck) with a Warner-Bratzler blade (2.8 mm wide). One section (10th–13th rib) of *longissimus* muscle was conditioned at 2 °C for 12 days, frozen at −18 °C, and transported to Bristol/UK for sensory analysis and colour and oxidative stability. Frozen samples for colour and lipid stability studies were thawed overnight in a 1±1 °C room. Three steaks 20 mm thick were sliced and put on drip pads and packed in a modified atmosphere (O_2/CO_2, 75:25). They were displayed in a cold room under simulated retail conditions (4 °C, 700 lx, 16 h light and 8 h darkness). Colour was measured at three positions on one steak daily (Minolta Chroma-meter CR 200, Minolta Camera, Milton Keynes, UK). After 5 and 10 days of display, a single steak was used for the analysis of lipid oxidation using the thiobarbituric acid reacting substances (TBARS) test of Tarladgis et al. (1960). For the fatty acid composition, muscle slices (6th/7th rib) were frozen rapidly and stored at −18 °C until lipid extraction. The method for fatty acid analysis by gas chromatography is described by Nuernberg et al. (2002).

3. Statistical analysis

All data were analysed by the least-squares method using the GLM procedures with fixed factors feeding and breed (SAS)®. All tables contain the least squares means (LSM) and the standard error (S.E.M.) of the

LSM. All statistical tests of LSM were performed for a significance level $\alpha \leq 0.05$.

4. Results

Animal daily live weight gain and meat quality results are summarised in Table 2. The daily gain of grass-based bulls was significantly lower than that of the concentrate group; hence, they were significantly older at the slaughter weight of 620 kg. GS bulls grew faster in both feeding groups (concentrate and grass-based) compared to GH bulls. Concentrate feeding resulted in higher intramuscular fat levels than grass-based feeding. Muscle pH was higher in GH bulls on the grass-based system. Muscle colour was darker in the animals on the grass-based diet and these animals had tougher meat as measured by shear force. Eating quality parameters were not greatly affected by diet or breed (Table 3). Grass-based animals tended to have tougher steaks than those finished off concentrates but this was compounded by an interaction between diet and breed. This interaction was due to the fact that the GH bulls on the grass-based system were considerably tougher than all three other groups (Table 4). Grass-based animals also had a significantly higher score for fishy, which is possibly a reflection of the greater amount of long chain *n*-3 PUFA in the meat of animals fed grass and linseed (Vatansever et al., 2000). There were only small differences between GH and GS breeds except for a slightly greater 'metallic' note in meat from GH. A further interaction occurred for 'bloodiness'. Whilst GH fed concentrates had a higher 'bloody' score than grass-based, the reverse was true for GS (Table 4). Overall liking was higher for the concentrate-fed animals.

The lipid oxidation (TBARS) results showed that the grass-based animals produced more oxidatively stable meat than the indoor-fed animals (Fig. 1), especially at 10 days of retail display. GS bulls produced slightly more stable meat than GH on the grass-based system. It should be noted that this analysis was done on meat previously frozen and values are higher than would be expected for meat analysed fresh (see for instance Vatansever et al., 2000).

The rate of colour deterioration during retail display of steaks was similar for all groups except GS fed concentrates, which initially declined faster (Fig. 2) than the other groups.

The different feeding regimes caused large differences in total intramuscular muscle fatty acids as shown in Table 2. The grass-based animals had less fat. Diet also caused significant changes in the fatty acid composition of intramuscular fat of *longissimus* muscle in GS and GH bulls (Table 5). The percentage of total *n*-3 fatty acids was significantly increased in bulls fed the grass-based diet compared with those fed concentrate. This also applied to C18:3*n*-3, C20:5*n*-3 and C22:6*n*-3. The ratio of *n*-6 to *n*-3 fatty acids was beneficially low in grass-based GH and GS bulls, 1.9 and 2.0, respectively, compared with 6.5 and 8.3. The relative proportions of C12:0, C14:0 and of the sum of

Table 2
Daily gain (kg/day), age (days) and meat quality parameters of *longissimus* muscle of German Holstein and German Simmental bulls

Numbers (*n*)	GH bulls concentrate		Grass-based		GS bulls concentrate		Grass-based		Significance ($P<0.05$)
	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	
	17		16		16		15		
Live weight at slaughter (kg)	619.8	2.7	624.0	2.8	623.4	2.8	620.2	2.9	
Age at slaughter (days)	594	8.1	732	8.3	495	8.3	680	8.6	B, F, B*F
Daily gain (kg/day)	1.15	0.01	0.87	0.01	1.4	0.01	0.9	0.01	B, F, B*F
Intramuscular fat (%)	2.67	0.24	2.30	0.25	2.61	0.25	1.51	0.26	F
pH_{24}	5.76	0.04	5.91	0.04	5.85	0.03	5.72	0.04	B*F
Colour (L*)	33.08	0.49	29.25	0.51	35.78	0.51	32.20	0.53	B,F
Shear force (kg) after 12 days conditioning	11.06	0.75	14.34	0.78	13.17	0.78	15.87	0.80	B,F

LSM—least square means, S.E.M.—standard error of LSM, B—significant influence of breed, F—significant influence of feed, B*F—significant interactions of breed*feed.

Table 3
Eating quality of grilled *longissimus* muscle steaks (0–100 scale) of German Holstein and German Simmental bulls

Attributes	Diet			Breed		
	Concentrate	Grass-based	Significance	GH	GS	Significance
Toughness	57.1	70.4	ns	64.0	63.6	ns
Juiciness	43.1	42.3	ns	42.8	42.6	ns
Beef	23.1	24.1	ns	23.8	23.4	ns
Abnormal	16.4	14.6	ns	15.4	15.6	ns
Greasy	12.7	11.2	ns	11.8	12.2	ns
Bloody	7.7	11.1	ns	9.4	9.5	ns
Livery	5.6	5.2	ns	5.7	5.1	ns
Metallic	7.2	7.5	ns	8.3	6.4	B
Bitter	2.6	2.8	ns	2.7	2.7	ns
Sweet	1.9	1.6	ns	1.7	1.8	ns
Rancid	2.7	3.1	ns	2.8	2.9	ns
Fishy	1.7	4.3	F	3.2	2.9	ns
Acidic	11.6	11.5	ns	11.6	11.5	ns
Vegetable/grassy	5.9	4.7	ns	5.3	5.2	ns
Dairy	6.9	5.2	ns	5.2	6.9	ns
Hedonic						
Overall liking	16.2	12.2	F	14.9	13.5	ns

B—significant influence of breed, F—significant influence of feed.

saturated fatty acids were not influenced by the feeding system. The percentage of palmitic acid (C16:0) was significantly decreased on the grass-based system. Grass-based feeding resulted in a higher percentage of C18:1*trans* isomers in both breeds. There was no influence of feeding on the sum of muscle *n*-6 fatty acids or on C18:2*n*-6 or C20:4*n*-6. GS bulls showed a lower percentage of C12:0, C14:0, and a higher percentage of all *n*-6 fatty acids in *longissimus* muscle compared to GH bulls. There was no influence of breed on the percentages of C16:0, C18:0, the sum of SFA, UFA and the sum of C18:1*trans* isomers. GS bulls accumulated a higher proportion of *n*-3 fatty acids, PUFA and *n*-6 fatty acids than GH, whilst C16:1 and C18:1*cis*-9 percentage were lower. Interactions between feeding and breed were noted for C18:0, C20:5*n*-3, C22:5*n*-3 and the ratio of *n*-6/*n*-3.

Table 4
Interactions for the eating quality of grilled *longissimus* muscle of German Holstein and German Simmental bulls beef loin steaks

Attributes	Concentrate		Grass-based		
	GH	GS	GH	GS	S.E.M.
Toughness	54.4^{a}	59.9^{b}	73.6^{d}	67.2^{c}	2.50
Bloody	8.7^{ab}	6.7^{a}	10.0^{bc}	12.2^{c}	1.29

Values are the means derived from analysis of variance with diet and breed as factors and panels treated as a block structure with 15 replications.

The percentage concentration of CLA*cis*-9,*trans*-11 (0.87% vs. 0.72% in GS, 0.84% vs. 0.75% in GH) in muscle was significantly higher in animals on the grass-based system (Table 6). There was no influence of feeding grass/linseed when the absolute content in muscle was calculated, explained by the lower fat content of muscle in grass-based animals. GH bulls accumulated a higher amount of CLA*cis*-9,*trans*-11 (17.1 mg concentrate and 17.3 mg/100 g muscle grass-based) compared with GS bulls (13.3 mg vs. 11.5 mg/100 g, respectively).

5. Discussion

Growth performance of GS and GH bulls was lower on the grass-based system compared with concentrates. The modification of beef production systems to substitute energy-dense concentrate ingredients with grass of lower energy concentration resulted in carcasses with lower intramuscular fat content. It is possible that bulls were unable to deposit sufficient lipid to ensure consumer acceptability, with regard to flavour, toughness and tenderness.

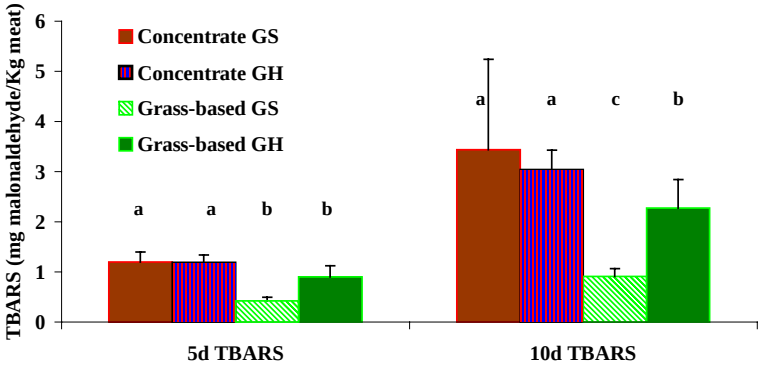

Fig. 1. Effect of breed and diet on lipid oxidation (TBARS, mg malonaldehyde/kg meat) in *longissmus* muscle steaks after 5 and 10 days simulated retail display in modified atmosphere packs. Columns with different letters are significantly different ($P<0.05$).

Bulls on the grass-based system had tougher beef compared with concentrate-fed bulls. The WBSF values measured were high compared with other studies (Raes et al., 2003; French et al., 2001). This may partly be due to different methodology compared with other published work (e.g. a higher cooking temperature) but bulls on the grass-based system were also older than the concentrate-fed animals and the intramuscular fat content of *longissimus* muscle was lower. It is recognised in the literature that age at slaughter influences tenderness. A reduction in tenderness has been reported as age increased from 8 to 10 months in cattle (Purchas et al., 2002). Wheeler et al. (2002) calculated correlation coefficients between tenderness rating and total collagen of −0.12 (raw steak) and −0.45 (cooked steak) in beef *longissimus*. Grass-based bulls in this study were 4–6 months older than those fed concentrate and hence the differences in tenderness may reflect more collagen. Tenderness evaluation by the taste panel corresponded with the WBSF values. Larick et al. (1987) reported that grain-fed beef cattle produced more tender and better flavoured meat than forage-fed animals. The results confirm other work which shows that bulls of over 16 months are likely to produce tough beef (Fisher et al., 2001).

French et al. (2001) investigated the meat quality from cattle finished on grass alone, on concentrates or on various combinations of both. There were no differences between diets for colour, WBSF or sensory attributes in muscle. French et al. (2001) calculated a negative correlation between WBSF and carcass growth rate (−0.31). In our study, the daily gain of the grass-based bulls was significantly lower than in intensive fed animals. However, in contrast to

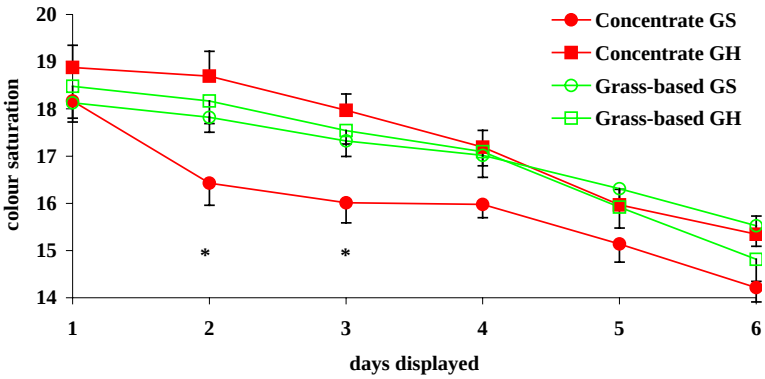

Fig. 2. Effect of breed and diet on colour saturation of *longissmus* muscle steaks during simulated retail display in MA packs. *Indicates significantly lower values in concentrated-fed GS bulls ($P<0.05$).

Table 5
Total fatty acid composition (%) of intramuscular fat in *longissimus* muscle of German Holstein and German Simmental bulls

	German Holstein bulls				German Simmental bulls				Significance ($P<0.05$)
	Concentrate		Grass-based		Concentrate		Grass-based		
	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	
C12:0	0.05	0.003	0.06	0.003	0.05	0.003	0.04	0.003	B
C14:0	2.37	0.10	2.23	0.10	1.96	0.10	1.82	0.10	B
C16:0	25.10	0.40	23.25	0.41	24.26	0.41	22.56	0.43	F
C16:1	3.70	0.13	2.88	0.13	3.20	0.13	2.39	0.14	B, F
C18:0	14.56	0.45	18.28	0.46	16.80	0.46	17.64	0.47	F, B*F
C18:1*cis*9	39.30	0.79	34.10	0.81	37.28	0.81	31.69	0.84	B, F
C18:2*n*-6	4.11	0.53	4.32	0.55	5.22	0.55	6.56	0.57	B
C18:3*n*-3	0.34	0.13	1.67	0.13	0.46	0.13	2.22	0.14	B, F
C20:3*n*-6	0.32	0.05	0.33	0.05	0.39	0.05	0.51	0.05	B
C20:4*n*-6	1.43	0.23	1.45	0.24	1.74	0.24	2.45	0.24	B
C20:5*n*-3	0.14	0.07	0.58	0.08	0.08	0.08	0.94	0.08	B, F, B*F
C22:4*n*-6	0.19	0.02	0.10	0.02	0.27	0.02	0.17	0.02	B, F
C22:5*n*-3	0.36	0.09	0.80	0.09	0.29	0.09	1.321	0.10	B, F, B*F
C22:6*n*-3	0.09	0.02	0.15	0.02	0.05	0.02	0.169	0.02	F
Sum SFA[a]	43.61	0.66	45.55	0.68	44.49	0.68	43.91	0.71	
Sum UFA[b]	56.46	0.66	54.45	0.68	55.51	0.68	56.09	0.71	
Sum PUFA[c]	7.47	1.02	9.71	1.05	9.07	1.05	14.29	1.08	B, F
Sum C18:1trans[d]	2.83	0.23	4.37	0.24	3.19	0.24	4.28	0.24	F
Sum *n*-3 FA[e]	0.96	0.29	3.25	0.30	0.90	0.30	4.70	0.31	B, F
Sum *n*-6 FA[f]	6.14	0.82	6.30	0.85	7.73	0.85	9.80	0.88	B
n-6/*n*-3 ratio[g]	6.49	0.14	1.94	0.15	8.34	0.15	2.04	0.15	B, F, B*F

B—significant influence of breed, F—significant influence of feed, B*F—significant interactions of breed*feed.
[a] Sum of saturated fatty acids: C10:0+C11:0+C12:0+C13:0+C14:0+C15:0+C16:0+C17:0+C18:0+C20:0+C21:0+C22:0+C23:0+C24:0.
[b] Sum of unsaturated fatty acids: C14:1+C15:1+C16:1+C17:1+C18:1*trans*+C18:1*cis*9+C18:1*cis*11+C18:2*trans*+C18:2-6+C18:3*n*-3+C18:4*n*-3+C20:3*n*-6+C20:4*n*-6+C20:5*n*-3+C22:1+C22:4*n*-6+C22:5*n*-3+C22:6*n*-3+*cis*9,tr11CLA+C18:3*n*-6+C20:2*n*-6+C20:3*n*-3+C22:2*n*-6+C24:1.
[c] Sum of *n*-3 and *n*-6 fatty acids.
[d] Sum of the isomers C18:1*trans*6–*trans*11.
[e] Sum of C20:3*n*-3+C22:6*n*-3+C22:5*n*-3+C20:5*n*-3+C18:4*n*-3+C18:3*n*-3.
[f] Sum of C22:2*n*-6+C20:2*n*-6+C18:3*n*-6+C22:4*n*-6+C20:3*n*-6+C18:2*n*-6+C20:4*n*-6.
[g] Quotient of the sum of *n*-6 and *n*-3 fatty acids.

the Irish experiment using steers (French et al., 2001), we did not find a relationship between daily gain and WBSF (r=0.08).

Bulls fed on the grass-based system including pasture showed a darker muscle colour than concentrate-fed animals. Varnam and Sutherland (1995)

Table 6
CLA*cis*-9,*trans*-11* concentration in *longissimus* muscle of German Holstein and German Simmental bulls

	German Holstein bulls				German Simmental bulls				Significance ($P<0.05$)
	Concentrate		Grass-based		Concentrate		Grass-based		
	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	LSM	S.E.M.	
	n=17		n=16		n=16		n=15		
CLA *cis*-9,*trans*-11 (%)	0.75	0.04	0.84	0.04	0.72	0.04	0.87	0.04	F
CLA*cis*-9,*trans*-11 (mg/100 g muscle)	17.11	1.72	17.34	1.77	13.32	1.77	11.51	1.83	B

B—significant influence of breed, F—significant influence of feed.
* Coeluation with C18:2*trans*-7,*cis*-9 and C18:2*trans*-8,*cis*-10.

hypothesized that grass-fed animals have more muscle myoglobin, due to the higher physical activity compared to indoor kept concentrate-fed bulls. Vestergaard et al. (2000) found a higher proportion of oxidative fibres and a darker meat colour in pasture-fed young bulls compared to grain-fed animals. Raes et al. (2003) also reported a paler colour in Belgian Blue beef (intensive fed) than Irish and Argentine beef (grass-based).

The oxidative stability of muscle from grass-based bulls was significantly higher compared with concentrate-fed animals. It has been shown that animals kept on pasture have higher concentrations of vitamin E in the muscle. Feeding grass silage caused a higher vitamin E concentration in beef compared to maize silage (O'Sullivan et al., 2002; Schwarz et al., 2003). GS produced slightly more stable meat than GH bulls. American research also showed that Holsteins produced less stable meat than beef breeds (Arnold et al., 1992; Garber et al., 1996).

Discussion of the nutritional value of beef has been relatively controversial. Often more attention has been focused on negative nutritional concerns such as saturated fat and cholesterol. Metabolic studies have long established that the type of fat, but not the total amount of fat, predicts serum cholesterol levels (Sanders, 2003). In addition, results from epidemiological studies and controlled clinical trials have indicated that replacing saturated fat and *trans* fatty acids with unsaturated fat, especially *n*-3 fatty acids, is more effective in lowering the risk of coronary heart disease than simply reducing total fat consumption (Renaud and Lanzmann-Petithory, 2002; Hu and Willett, 2002; Sanders, 2003). Feeding strategies that induce a decrease in saturated fat and enhance the *n*-3 fatty acids of intramuscular fat would improve the nutritional value of beef. The objective of this study was to establish whether the grass and linseed concentrate feeding system is sufficient to accumulate muscle *n*-3 fatty acids, especially the long chain *n*-3 PUFA and CLA *cis*-9,*trans*-11. Despite the biohydrogenation of C18:3*n*-3 in the rumen, the linolenic acid contained in grass and linseed was deposited at higher concentrations in muscle of bulls on the grass-based diet. Bulls grazing on pasture and finished on a diet containing linseed accumulated two to three fold higher concentrations of total *n*-3 fatty acids in their muscles compared to those fed concentrate. The increased concentrations of C20:5*n*-3, C22:5*n*-3 and C22:6*n*-3 in muscle of animals fed on grass suggests that the high availability of 18:3 in the diet has resulted in an enhanced synthesis of these *n*-3 long chain PUFA. In our experiment, there was a decrease in the amounts of C18:2*n*-6 and all long chain *n*-6 fatty acids in muscle fat in the grass-based system. However, the percentages of *n*-6 fatty acids were not different between the systems. This is explained by the lower total fatty acid concentration in the grass-based groups, allowing long chain phospholipid fatty acids to dominate total lipid. In some studies, increases in *n*-3 PUFA are matched by reductions in *n*-6 PUFA, showing competition between these fatty acids for the same set of elongation and desaturation enzymes. For example, Lorenz (2004) showed that the proportion of C20:4*n*-6 in the red blood cell phospholipid fraction of GS bulls (18 months old) was significantly decreased after feeding on pasture compared to concentrate-fed bulls (6.8% vs. 3.4%), whilst EPA was elevated 0.5% vs. 3.2%, respectively. These inverse relationships were not found here.

The consumption of beef from grass-based bulls with increased *n*-3 fatty acid concentrations can contribute to human daily requirements for these fatty acids, especially C18.3*n*-3, EPA, DPA and DHA. Meat, milk and eggs are the only sources of long-chain *n*-3 fatty acids in the diet for people who do not consume fish. The unchanged concentration of saturated fatty acids is also positive for human nutrition although the percentage of C18:1*trans* fatty acids was increased. It has been shown that the intake of *trans* fatty acids increases the low density lipoprotein cholesterol, decreases the high density lipoproteins and influences lipoprotein a (Valenzuela and Morgado, 1999). At present, it has not been shown which isomer of the *trans* fatty acids is responsible for the negative effects on blood lipids. However, there is some evidence that the dominant *trans* isomer in meat and milk (*trans* vaccenic acid, C18:1*trans*-11) is not a significant risk factor for cardiovascular disease compared with those trans fatty acids arising from the chemical hardening of oils (Willett et al., 1993). In this study, feeding the grass-based diet increased the relative proportion but not the absolute concentration of the C18:1*trans* isomers because total muscle fatty acids were reduced.

In contrast to *trans* fatty acids which are associated with coronary heart disease, many beneficial effects

have been reported for CLA (Kritchevsky, 2000; Banni et al., 2002; Parodi, 2002). Dietary intake of *trans* vaccenic acid for 5 weeks by healthy subjects increased the CLA in total serum (Salminen et al., 1998). This means that the C18:1*trans*-11 in meat can play a positive role for the endogenous synthesis of CLA.

The biohydrogenation process in the rumen is affected by many factors such as feed intake, diet composition, the type and source of carbohydrates, the degree of fatty acid unsaturation, the forage to grain ratio and the nitrogen content of the diet (Latham et al., 1971, 1972; Dhiman et al., 1999; Piperova et al., 2000; Chouinard et al., 2001; Chilliard et al., 2001; Song and Kenelly, 2003). Regardless of the origin of CLA isomers, changes in the biohydrogenation process remain an important route to accumulation of CLA *cis*-9,*trans*-11 and vaccenic acid (C18:1*trans*-11) in milk, muscle and fatty tissues in ruminants. Under our experimental conditions, the percentage CLA concentration in beef muscle was significantly increased by grazing on pasture and feeding linseed. Feeding linseed to steers also increased CLA *cis*-9,*trans*-11 in muscle in a study by Enser et al. (1999). Replacing barley grain with linseed in the diet of lactating cows for two weeks also increased the 18:3 and CLA *cis*-9,*trans*-11 percentage in milk (Soita et al., 2003). Further studies are required to examine the accumulation of CLA isomers in beef under various dietary and feeding conditions.

6. Conclusion

The results of the study show that feeding grass and linseed to cattle can have positive effects on the fatty acid profile of their meat (higher *n*-3 fatty acid and CLA percentages), resulting in a healthier product, but the slower growth of bulls on a grazing system produces tougher meat which would have to be addressed. It is necessary to bring the positive benefits of grass-fed beef to the attention of the public, medical profession, producers and consumers.

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