

## Factors affecting the variation in fatty acid concentrations in lean beef from grass-fed cattle in New Zealand and the implications for human health

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conjugated linoleic, and docosahexaenoic acids and low CV for the saturated (SATFA) and monounsaturated FA (MUFA), and intermediate CV for other FA. There were significant effects of muscle and animal types in Experiment 1 and of breed, sire, sex, and year-born in Experiment 2 on the composition and content of individual and groups of FA, especially the polyunsaturated FA (PUFA). The n-6:n-3, PUFA:SATFA, and MUFA:SATFA ratios, and the indices for atherogenicity and thrombogenicity, traits that have human health implications, were affected by factors in both experiments, but absolute differences were small. The conclusions were that the FA composition of lean grass-fed beef could be changed by traditional means to improve the human health image of beef, but the impact would be small and progress slow. More progress was likely from selecting for beneficial FA than against undesirable SATFA.

**Keywords** beef; fat; fatty acids; animal variation; human health

**Abstract** Lean beef from grass-fed cattle was analysed for fatty acid (FA) content to determine the between-animal variation and the effects of various traits on FA composition, and indices and FA ratios that have human health implications. In Experiment 1, samples were from three muscles from five bulls, five cows, and five heifers. In Experiment 2, samples were from the *m. longissimus lumborum* of 50 <sup>3</sup>/<sub>4</sub> Jersey <sup>1</sup>/<sub>4</sub> Limousin and 50 <sup>3</sup>/<sub>4</sub> Limousin <sup>1</sup>/<sub>4</sub> Jersey cattle, born over 2 years and sired by two bulls. The heifers and steers grazed on similar pastures until slaughter. In both experiments, after adjusting for differences in total FA content of the meat, there were large coefficients of variation (CV) for *trans*-vaccenic, *cis*-9 *trans*-11

### INTRODUCTION

Consumption of beef and other red meats is promoted for the health benefits because of their vitamin and mineral content, but criticised for the total amount of fat and the high proportion of saturated fatty acids (SATFA) (Wood & Enser 1997). Higgs (2000) has reported on the reduction in the fat content of beef on offer to consumers arising from the trimming of excess fat and the breeding and management by farmers to produce leaner cattle. However, the problem of high SATFA and low polyunsaturated fatty acid (PUFA) content in beef remains (Ulbricht & Southgate 1991). Some dietary SATFA promote development of atherosclerosis leading to coronary heart disease (CHD), whereas PUFA reduces the risk of CHD (Ulbricht & Southgate 1991). Not only is the total PUFA dietary intake important, but a growing emphasis is being placed on the imbalance in the western diet

of the n-6:n-3 ratio of PUFA which can range from 10:1 to 20:1 compared with the recommended ratio of 4:1–1:1 (Simopoulos 1996).

Some fatty acids (FA) have beneficial effects on human health. Conjugated linoleic acid (CLA), especially the *cis*-9, *trans*-11 isomer, reduces the severity of cancer in a number of animal models that have used a range of acute carcinogenic stimulants (Belury 1995; Kritchevsky 2000). Other potential health benefits have been attributed to CLA, but the anti-carcinogenic effects are the most important (Kritchevsky 2000).

Ruminant products (meat and milk) contain high natural concentrations of CLA (Chin et al. 1992). Initially, it was believed the CLA in meat and milk arose directly from CLA produced in the rumen during the bio-hydrogenation of linoleic to stearic acid (Kritchevsky 2000). Recent research suggests, however, that most CLA in the rumen is hydrogenated to *trans*-vaccenic acid (TVA), but some TVA escapes further hydrogenation and is absorbed in the small intestine. A proportion of this TVA is desaturated to CLA by delta-9 desaturase. (Corl et al. 2001). Dietary TVA, unlike other *trans*-

FA, is not associated with CHD in humans (Willett et al. 1993) and has been shown to be a precursor for CLA in mice (Santora et al. 2000) and humans (Salminen et al. 1998).

The long-chain n-3 FA, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), also have health benefits (Simopoulos 1996). These FA are synthesised in tissue from linoleic acid and docosapentaenoic acid (DPA), which can be converted to DHA or back to EPA (Simopoulos 1996). Meat, fish, fish oil, and eggs are the only significant dietary source of these long-chain n-3 PUFA for humans (Scollan et al. 2001). EPA reduces the potential for CHD by lowering blood triacylglycerol concentration and by forming eicosanoids that reduce blood clotting and promote vasodilation. This contrasts with arachidonic acid that forms eicosanoids that can promote blood clotting and vasoconstriction. There is also a specific requirement for DHA for neural development and visual acuity in infants and maintenance of brain function in the elderly (Simopoulos 1996).

The aims of the two experiments in this paper were to determine the FA content and composition of beef from grass-fed cattle in New Zealand, the variation that was present, and factors that influenced this variation. This information is required to determine whether farmers can use traditional strategies of animal selection, breeding, and management to improve the human health attributes of the FA composition of lean beef from grass-fed cattle.

**Table 1** A list of the abbreviations used in the paper for the fatty acids. The ratios and indices are calculated from the fatty acid content of the meat or proportion of fatty acids in the total fatty acid.

Abbreviations	Description
<i>c</i>	<i>cis</i>
<i>t</i>	<i>trans</i>
FA	fatty acid(s)
TFA	total fatty acid(s)
SATFA	saturated FA
MCSFA	medium-chain SATFA
OCSFA	odd-chain SATFA
LCSFA	long-chain SATFA
MUFA	monounsaturated FA
<i>t</i> -MUFA	<i>trans</i> MUFA
<i>c</i> -MUFA	<i>cis</i> MUFA
PUFA	polyunsaturated FA
CLA	conjugated linoleic acid(s)
TVA	<i>trans</i> -vaccenic acid ( <i>trans</i> -11 C18:1)
AA	arachidonic acid (C20:4 n-6)
EPA	eicosapentaenoic acid (C20:5 n-3)
DPA	docosapentaenoic acid (C22:5 n-3)
DHA	docosahexaenoic acid (C22:6 n-3)
M:S ratio	ratio of MUFA:SATFA
P:S ratio	ratio of PUFA:SATFA
n-6:n-3	ratio of omega-6 PUFA:omega-3 PUFA
A. index	index of atherogenicity
T. index	index of thrombogenicity

## MATERIALS AND METHODS

A list of the abbreviations used in this paper for the fatty acids and the ratios and indices calculated from the fatty acid content of the meat is presented in Table 1.

### Experiment 1

Five 30-month-old Hereford-Friesian bulls, five culled Friesian dairy cows older than 4 years, and five 20-month-old Simmental-Hereford heifers were selected in the yards of a local processing plant. Carcasses were weighed immediately after slaughter and meat samples collected after the carcasses had been in the chiller for 24 h. Samples were taken from three muscles from each of the 15 carcasses; the *m. semitendinosus* (ST), *m. longissimus lumborum* (LL), and *m. triceps brachii*

(*caput longum*) (TB). The samples were vacuum-packed, and stored at  $-20^{\circ}\text{C}$  until analysis.

## Experiment 2

Semen from two first-cross Jersey  $\times$  Limousin bulls (Sire A,  $n = 48$ ; Sire B,  $n = 52$ ) was used to inseminate pure-bred Jersey and Limousin cows, to generate 50  $^{3/4}$  Jersey  $^{1/4}$  Limousin ( $^{3/4}\text{J}$ ) and 50  $^{3/4}$  Limousin  $^{1/4}$  Jersey ( $^{3/4}\text{L}$ ) calves over 2 years; 1996 ( $n = 66$ ) and 1997 ( $n = 34$ ). Bull calves were castrated at birth, and after weaning heifer ( $n = 54$ ) and steer ( $n = 46$ ) calves from each breed were grazed on similar pastures at the Tokanui Research Station, near Hamilton. Cattle born in 1996 were slaughtered from August to November 1998, and cattle born in 1997 were slaughtered from September to October 1999. A sample of the LL at the 13th rib was removed 24 h after slaughter, vacuum-packed, and stored at  $-20^{\circ}\text{C}$  until analysis.

## Analyses of fatty acids

Muscle samples were dissected free of intermuscular fat and the epimysium, weighed, freeze dried, weighed again to determine the dry matter content of the meat, and then finely ground. Lipids were extracted from the freeze-dried samples by a modified Folch method (Folch et al. 1957). The saponification, methylation, and analyses of FA in the extracts were based on the methods of Slover & Lanza (1979) and the American Oil Chemists Society (2001). An internal standard of 2 mg tridecanoic acid (C13:0) in 2 ml isoctane was added to 10–25 ml of the extracted lipids. Lipids were saponified using methanolic NaOH and methylated using a freshly prepared methanolic  $\text{BF}_3$  solution. The dry isoctane solution of fatty acid methyl esters was stored in a refrigerator until analysed. For all steps in the procedure the extract was blanketed with nitrogen.

Gas-liquid chromatography (GLC) was performed with a Hewlett Packard model 6890 equipped with a flame ionisation detector and a SGE BPX70 column 120 m length, 0.25 mm i.d., and 0.25  $\mu\text{m}$  film thickness. A 1  $\mu\text{l}$  volume of the sample or standards was injected into the GLC with a split ratio of 50:1. Helium was used as the carrier gas at a linear velocity of 19  $\text{cm s}^{-1}$  or 1.2  $\text{ml min}^{-1}$  in a constant flow mode; the starting column pressure was 45 psi. The injector temperature was  $250^{\circ}\text{C}$  and the initial temperature on the column was  $130^{\circ}\text{C}$  increasing at  $1^{\circ}\text{C min}^{-1}$  to  $190^{\circ}\text{C}$  and then  $2^{\circ}\text{C min}^{-1}$  to  $245^{\circ}\text{C}$  and this temperature was held for 5 min.

The total run time was 95 min. Fatty acids were identified by comparing their retention time with known standards and using effective chain length calculations from data contained in technical publications for the SGE BPX 70 phase columns.

The relative delta-9 desaturase activity in the muscles can be estimated by desaturation indices (Malau-Aduli et al. 1997) and the following desaturation indices were calculated:

$$\text{desaturation-C16}[\text{desat-C16}] = (\text{C16:1})/(\text{C16:0} + \text{C16:1})$$

$$\text{desaturation-C18}[\text{desat-C18}] = (\text{C18:1})/(\text{C18:0} + \text{C18:1})$$

$$\text{desaturation-CLA}[\text{desat-CLA}] = (\text{CLA})/(\text{TVA} + \text{CLA})$$

The SATFA were grouped for statistical analyses of FA content of raw meat ( $\text{mg FA } 100 \text{ g}^{-1}$  raw meat) into MCSFA (C12:0, C14:0, C16:0), LCSFA (C18:0, C20:0, C22:0, C24:0), and OCSFA (C15:0, C17:0, C21:0, C23:0). The MUFA were grouped into *t*-MUFA (TVA plus other *t*-C18:1) and *c*-MUFA (C14:1–C17:1, C18:1 n-9, *c*-C18:1, C20:1–C24:1), and the PUFA included n-6 PUFA, n-3 PUFA, and CLA.

The ratios for n-6:n-3, P:S, and M:S were calculated from the respective FA content of raw meat. Attempts to develop better indices of the potential health attributes of foods containing a mixture of FA have been made by Ulbricht & Southgate (1991) with their indices of atherogenicity and thrombogenicity. The  $\text{mg FA } 100 \text{ g}^{-1}$  raw meat was used to calculate the indices and the multiplier coefficients are those of Ulbricht & Southgate (1991).

$$\text{A. index} = \frac{(\text{C12:0}) + 4 \times (\text{C14:0}) + (\text{C16:0})}{(\text{MUFA} + \text{PUFA})}$$

$$\text{T. index} = \frac{(\text{C12:0} + \text{C16:0} + \text{C18:0})}{0.5 \times (\text{MUFA} + \text{n-6 PUFA}) + 3 \times (\text{n-3 PUFA}) + \frac{(\text{n-3 PUFA})}{(\text{n-6 PUFA})}}$$

## Statistical analyses

To remove the effect of differences in TFA content of the meat on the content and composition of individual and groups of FA, suitable correction factors needed to be identified. Preliminary data analyses indicated linear increases in the content of all groups of FA and increases in the proportions of SATFA, MUFA, CLA, and *t*-C18:2 n-6 with increasing  $\text{mg TFA } 100 \text{ g}^{-1}$  raw meat. In contrast, the proportions of C18:2, C18:3, C22:1, AA, EPA, DPA, and DHA decreased exponentially with increasing  $\text{mg TFA } 100 \text{ g}^{-1}$  raw meat in both experiments. The reciprocal of  $\text{mg TFA } 100 \text{ g}^{-1}$  raw meat produced the highest correlation with each of

these PUFA ( $r = 0.81-0.94$ ;  $P < 0.001$  in Experiment 1 and  $r = 0.92-0.98$ ;  $P < 0.001$  in Experiment 2) out of the four transformations evaluated (square root, log, reciprocal, and reciprocal of the square root). Therefore, the correction factor used as covariate for the content of all groups of FA and ratios and indices calculated from these FA, and for the proportion of all SATFA, MUFA, CLA, *t*-C18:2 n-6, and desaturation indices, was mg TFA 100 g<sup>-1</sup> raw meat. The reciprocal of mg TFA 100 g<sup>-1</sup> raw meat was used as covariate for the proportions of the other PUFA. Correlations and adjusted coefficients of variation (Adj. CV) were calculated using residual values for the traits generated from linear regressions with the respective correction factor included in the model. Correlations significant at  $P < 0.05$  are only reported when the comparisons were significant in both experiments (Sankoh et al. 1997).

Split-plot analyses (Genstat 1993) were used in Experiment 1 for the analyses of lipid, TFA, and groups of FA content in raw meat, calculated ratios, and indices (Table 3), and the FA composition of the extracted TFA and the desaturation indices (Table 4). The animal type (age and gender) was the upper level with the mean of the three muscles being compared, and the muscles and the animal type by muscle interaction was compared in the lower level. The upper level covariates indicate the relationships between the covariate and each variable among animals, whereas the lower level covariates indicate the relationship between the covariate and each variable after removing animal

effects. Carcass weight was analysed by analyses of variance.

In Experiment 2, the same variables used in Experiment 1 were analysed as a  $2 \times 2 \times 2 \times 2$  factorial (Genstat 1993) with breed, sex, year-born, and sire as the main factors together with the interactions.

The relevant covariates as outlined above were included in the analyses in both experiments. Means are presented with standard error of the mean (SEM).

## RESULTS

### Fatty acids assayed

The FA identified include those in Tables 4 and 8 plus C14:1, C15:1, C17:1,  $\gamma$ -C18:3 n-6, C20:0, C20:1, C20:2 n-6, C20:3 n-6, C21:0, C22:0, C22:2 n-6, C23:0, C24:0, and C24:1. These latter FA were in concentrations of less than 0.2 g 100 g<sup>-1</sup> TFA and their individual values are not presented. The only CLA isomer identified was *c*-9 *t*-11 CLA. Unknown FA consists of unidentified FA peaks on the GLC printout and were  $5.7 \pm 1.2$  and  $6.8 \pm 1.1$  g 100 g<sup>-1</sup> TFA in Experiments 1 and 2, respectively.

### Experiment 1

Cows had lower ( $P < 0.001$ ) carcass weights ( $210 \pm 29$  kg) than heifers ( $268 \pm 15$  kg) and bulls ( $295 \pm 20$  kg) with no significant difference in carcass weight between the latter two. The heifers had a higher ( $P < 0.001$ ) lipid content in the raw meat

**Table 2** Mean, minimum, and maximum content and coefficient of variation (CV) for TFA and individual and groups of FA (mg 100 g<sup>-1</sup> raw meat) and extracted lipids (g 100 g<sup>-1</sup> raw meat) in Experiment 1. Adjusted CVs (Adj. CV) were calculated after correcting the contents of FA for mg TFA 100 g<sup>-1</sup> of raw meat. (Key to abbreviations is given in Table 1.)

	Mean	Minimum	Maximum	CV	Adj. CV
Lipids (g 100 g <sup>-1</sup> )	2.3	0.8	5.3	44	–
TFA (mg 100 g <sup>-1</sup> )	1900	635	4693	55	–
SATFA	801	227	2084	57	5
MUFA	820	210	2096	63	7
n-6 PUFA	94	59	170	26	24
n-3 PUFA	70	44	112	25	15
TVA	29	3	227	128	92
CLA	4	0	27	110	74
AA	24	17	38	19	19
EPA	5	2	10	39	23
DPA	17	10	23	20	18
DHA	3	0	7	55	55

than cows and bulls (3.23, 2.09, and  $1.60 \pm 0.23$  g lipid  $100 \text{ g}^{-1}$  raw meat, respectively). The TB had a higher ( $P < 0.001$ ) lipid content in the raw meat

than the ST and LL (2.76, 2.15, and  $2.06 \pm 0.15$  g lipid  $100 \text{ g}^{-1}$  raw meat, respectively).

There were large ranges in the content of

**Table 3** Mean and SE for the content of TFA and groups of FA (mg  $100 \text{ g}^{-1}$  raw meat) and their ratios and indices for raw meat from bulls, cows, and heifers (animal type) and from the *m. semitendinosus* (ST), *m. longissimus lumborum* (LL), and *m. triceps brachii (caput longum)* (TB) in Experiment 1. The covariate mg TFA  $100 \text{ g}^{-1}$  raw meat was used to correct for differences among samples in TFA for all variables except TFA. The significance of the upper and lower level covariates from the split plot analyses and the sign of the covariate coefficients are presented. NS, not significant; \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ . Comparisons within a row with different superscripts are significantly different at  $P < 0.05$ . (Key to abbreviations given in Table 1).

Fatty acid	Animal type			SE	Upper covar.			Muscle			SE	Lower covar.		
	Bull	Cow	Heifer		Sig. diff.	Sig. diff.	Sign	LL	ST	TB		Sig. diff.	Sig. diff.	Sign
TFA	1159 <sup>a</sup>	1645 <sup>a</sup>	2895 <sup>b</sup>	241	***	—		1607 <sup>a</sup>	1770 <sup>a</sup>	2321 <sup>b</sup>	155	**	—	
MCSFA	477 <sup>ab</sup>	515 <sup>a</sup>	440 <sup>b</sup>	13	**	***	+	492 <sup>a</sup>	474 <sup>b</sup>	466 <sup>b</sup>	6	*	***	+
LCSFA	283 <sup>ab</sup>	257 <sup>a</sup>	357 <sup>b</sup>	14	***	***	+	301	297	300	8	NS	***	+
OCSFA	23 <sup>ab</sup>	20 <sup>a</sup>	31 <sup>b</sup>	3	*	***	+	25	25	25	1	NS	***	+
SATFA	783	793	828	21	NS	***	+	817	796	790	9	NS	**	+
<i>t</i> -MUFA	33	25	49	19	NS	NS		36	36	34	4	NS	***	+
<i>c</i> -MUFA	804	822	728	43	NS	***	+	791	792	770	14	NS	***	+
MUFA	836	847	776	30	NS	***	+	827	828	806	11	NS	***	+
n-6 PUFA	97 <sup>ab</sup>	81 <sup>a</sup>	103 <sup>b</sup>	5	**	NS		83 <sup>a</sup>	88 <sup>a</sup>	110 <sup>b</sup>	4	***	**	+
n-3 PUFA	66	66	78	4	NS	NS		62 <sup>a</sup>	70 <sup>b</sup>	78 <sup>c</sup>	2	***	***	+
PUFA	177 <sup>ab</sup>	162 <sup>a</sup>	197 <sup>b</sup>	8	*	NS		160 <sup>a</sup>	173 <sup>a</sup>	203 <sup>b</sup>	6	***	***	+
n-6:n-3	1.49 <sup>a</sup>	1.23 <sup>b</sup>	1.34 <sup>ab</sup>	0.06	**	**	—	1.35 <sup>a</sup>	1.28 <sup>a</sup>	1.44 <sup>b</sup>	0.03	***	NS	
P:S	0.33 <sup>a</sup>	0.24 <sup>b</sup>	0.28 <sup>ab</sup>	0.02	**	***	—	0.25	0.31	0.30	0.02	NS	**	—
M:S	1.03	1.03	0.91	0.06	NS	*	+	0.98	1.01	0.99	0.02	NS	NS	
A. index	0.56 <sup>a</sup>	0.68 <sup>b</sup>	0.60 <sup>ab</sup>	0.05	*	NS		0.64 <sup>a</sup>	0.60 <sup>b</sup>	0.61 <sup>ab</sup>	0.01	*	**	+
T. index	1.07	1.14	1.16	0.06	NS	*	+	1.19 <sup>a</sup>	1.08 <sup>b</sup>	1.10 <sup>b</sup>	0.03	*	***	+

**Table 4** Mean and SE for FA composition (g  $100 \text{ g}^{-1}$  TFA) and desaturation indices for meat from bulls, cows, and heifers (animal type) from the *m. semitendinosus* (ST), *m. longissimus lumborum* (LL), and *m. triceps brachii (caput longum)* (TB) in Experiment 1. The significance and the sign of the coefficient for the upper and lower level covariates from the split-plot analyses are presented. The covariate used was mg TFA  $100 \text{ g}^{-1}$  raw meat for analyses of FA and desaturation indices in the upper part of the table and the reciprocal of mg TFA  $100 \text{ g}^{-1}$  raw meat for FA in the lower part of the table. NS, not significant; \*,  $P < 0.05$ ; \*\*,  $P < 0.01$ ; \*\*\*,  $P < 0.001$ . Comparisons within a row with different superscripts are significantly different at  $P < 0.05$ . (Key to abbreviations is given in Table 1.)

Fatty acid	Animal type			SE	Upper covar.			Muscle			SE	Lower covar.		
	Bull	Cow	Heifer		Sig. diff.	Sig. diff.	Sign	LL	ST	TB		Sig. diff.	Sig. diff.	Sign
C12:0	0.02 <sup>a</sup>	0.06 <sup>b</sup>	0.05 <sup>ab</sup>	0.01	*	NS		0.05	0.03	0.05	0.006	NS	*	+
C14:0	1.82 <sup>ab</sup>	2.61 <sup>a</sup>	1.68 <sup>b</sup>	0.22	***	NS		2.06 <sup>ab</sup>	1.91 <sup>a</sup>	2.14 <sup>b</sup>	0.06	*	***	+
C16:0	21.9 <sup>a</sup>	24.4 <sup>b</sup>	22.0 <sup>ab</sup>	0.8	*	NS		23.7 <sup>a</sup>	22.6 <sup>b</sup>	22.0 <sup>b</sup>	0.3	**	NS	
C16:1	2.85 <sup>a</sup>	3.68 <sup>a</sup>	1.52 <sup>b</sup>	0.32	***	*	+	2.78	2.71	2.57	0.12	NS	NS	
C17:0	0.82 <sup>ab</sup>	0.70 <sup>a</sup>	0.96 <sup>b</sup>	0.06	*	NS		0.81	0.83	0.83	0.01	NS	***	+
C18:0	14.78 <sup>a</sup>	13.37 <sup>a</sup>	17.60 <sup>b</sup>	0.77	**	NS		15.37	14.89	15.49	0.35	NS	*	+
Desat-C16	0.11 <sup>a</sup>	0.13 <sup>a</sup>	0.07 <sup>b</sup>	0.01	***	*	+	0.10	0.11	0.10	0.00	NS	NS	
Desat-C18	0.68 <sup>ab</sup>	0.71 <sup>a</sup>	0.64 <sup>b</sup>	0.02	*	*	+	0.68	0.68	0.67	0.01	NS	NS	
Desat-CLA	0.15 <sup>ab</sup>	0.17 <sup>a</sup>	0.11 <sup>b</sup>	0.01	*	NS		0.14	0.15	0.14	0.01	NS	NS	
C18:2 n-6	5.47 <sup>a</sup>	3.62 <sup>b</sup>	4.27 <sup>a</sup>	0.28	***	***	+	4.04 <sup>a</sup>	4.10 <sup>a</sup>	5.21 <sup>b</sup>	0.28	**	***	+
C18:3 n-3	2.84 <sup>a</sup>	1.89 <sup>b</sup>	2.66 <sup>a</sup>	0.19	**	***	+	2.17 <sup>a</sup>	2.31 <sup>a</sup>	2.66 <sup>b</sup>	0.11	**	***	+
C20:3 n-3	0.33 <sup>a</sup>	0.60 <sup>b</sup>	0.49 <sup>b</sup>	0.04	***	***	+	0.40 <sup>a</sup>	0.51 <sup>b</sup>	0.51 <sup>b</sup>	0.03	***	***	+
C22:1 n-9	1.31	1.42	1.18	0.12	NS	***	+	1.11 <sup>a</sup>	1.41 <sup>b</sup>	1.39 <sup>b</sup>	0.06	**	***	+
AA	1.54	1.86	1.76	0.11	NS	***	+	1.50 <sup>a</sup>	1.80 <sup>b</sup>	1.84 <sup>b</sup>	0.08	**	***	+
EPA	0.28	0.36	0.33	0.03	NS	*	+	0.28 <sup>a</sup>	0.35 <sup>b</sup>	0.34 <sup>b</sup>	0.01	***	***	+
DPA	1.06	1.28	1.17	0.10	NS	***	+	0.99 <sup>a</sup>	1.23 <sup>b</sup>	1.24 <sup>b</sup>	0.04	***	***	+



desaturation indices are presented in Table 4 for those FA with significant effects of animal type or muscle. The covariates were significant ( $P < 0.05$  to  $P < 0.001$ ) at the upper or lower level of the split-plot analyses for all FA and desaturation indices, except for C16:0 and the desaturation-CLA index. The coefficients for the covariates were all positive. There were no significant differences among animal types or among muscles for the proportions in the TFA of C15:0, CLA, C18:2 n-9, DHA, and all the C18:1 FA, including TVA. There were significant effects of animal type on the proportion in the TFA of most of the other SATFA and all the desaturation indices, but there were no effects of animal type on the proportions of long chain n-3 PUFA or MUFA in the TFA, except for C16:1. In contrast, there were significant effects of muscle type on the proportions of most PUFA in the TFA but no effects on the proportions of MUFA or SATFA, except for C14:0 and C16:0. Generally, the absolute differences in the proportions of the FA in the TFA caused by animal type and muscle type were small ( $<1 \text{ g } 100 \text{ g}^{-1}$  TFA) although for most FA the percentage differences were large. The maximum absolute difference was  $4.23 \text{ g } 100 \text{ g}^{-1}$  TFA for the difference in C18:0 between cows and heifers.

Correlations among FA after correcting for the TFA content of the raw meat are presented in Table 5. Notably, CLA was positively correlated with TVA and to a lesser extent C17:0. Among the OCSFA there were negative correlations between C17:0 and C14:0, C16:0, C16:1, and C18:1 n-9, and between the desaturation indices and C15:0 ( $r = -0.31$  to  $-0.66$ ;  $P < 0.001$ ) and C17:0 ( $r = -0.57$  to  $-0.83$ ;

$P < 0.001$ ). The desaturation indices were positively correlated to each other ( $r = 0.64$  to  $0.77$ ;  $P < 0.001$ ).

## Experiment 2

Carcass weights were lower ( $P < 0.001$ ) for  $3/4\text{J}$  than for  $3/4\text{L}$  ( $202$  versus  $268 \pm 4 \text{ kg}$ , respectively), and lower for heifers than for steers ( $219$  versus  $251 \pm 4 \text{ kg}$ , respectively). There was a higher ( $P < 0.001$ ) percentage lipid in the raw meat from  $3/4\text{J}$  than from  $3/4\text{L}$  ( $5.00$  versus  $2.35 \pm 0.24 \text{ g } 100 \text{ g}^{-1}$  raw meat, respectively). The carcass weight of 1997-born animals was higher ( $P < 0.001$ ) than those born in 1996 ( $243$  versus  $227 \pm 4 \text{ kg}$ , respectively) and progeny sired by Sire B had higher ( $P < 0.001$ ) carcass weights than those sired by Sire A ( $240$  versus  $228 \pm 4 \text{ kg}$ , respectively).

The mean and range in lipid and TFA content of the raw meat were higher than in Experiment 1 but again there were high CVs for the individual and groups of FA (Table 6). The content of all individual and groups of FA in the raw meat, except for DHA, increased ( $P < 0.05$  to  $P < 0.001$ ) with increasing content of TFA  $100 \text{ g}^{-1}$  of raw meat. After correcting for differences in TFA in the raw meat the Adj. CV again fell into three groups: the low values for SATFA and MUFA, the high values for TVA, CLA, and DHA, and the intermediate values for the rest of the individual and groups of FA. The mean and maximum content of DHA and EPA, and of CLA in the raw meat were again low compared with the content of their precursors, DPA and TVA, respectively.

The breed, sex, sires, and year-born of the cattle all had significant effects on the content of SATFA

**Table 6** Mean, minimum, and maximum content and coefficient of variation (CV) for TFA and individual and groups of FA ( $\text{mg } 100 \text{ g}^{-1}$  raw meat) and extracted lipids ( $\text{g } 100 \text{ g}^{-1}$  raw meat) in Experiment 2. Adjusted CVs (Adj. CV) were calculated after correcting the content of FA for  $\text{mg TFA } 100 \text{ g}^{-1}$  of raw meat. (Key to abbreviations is given in Table 1.)

	Mean	Minimum	Maximum	CV	Adj. CV
Lipids ( $\text{g } 100 \text{ g}^{-1}$ )	3.6	1.0	10.6	54	–
TFA ( $\text{mg } 100 \text{ g}^{-1}$ )	3148	506	12587	63	–
SATFA	1349	175	5359	65	6
MUFA	1432	184	6207	68	6
n-6 PUFA	77	47	127	21	11
n-3 PUFA	67	40	141	25	10
TVA	46	5	158	73	30
CLA	11	2	35	69	30
AA	16	11	24	16	16
EPA	5	3	10	30	16
DPA	19	14	27	13	13
DHA	2	0	3	31	31

**Table 7** Mean and SE for the content of total FA, individual and groups of FA (mg 100 g<sup>-1</sup> raw meat) and their ratios and indices for samples from the *m. longissimus lumborum* (LL) from <sup>3</sup>/<sub>4</sub>J and <sup>3</sup>/<sub>4</sub>L heifers and steers born in 1996 or 1997 and sired by Sire A or Sire B in Experiment 2. The covariate mg TFA 100 g<sup>-1</sup> raw meat was used to correct for differences among samples in TFA content for all variables except TFA. <sup>a</sup> indicates a significant year-born by breed interaction; NS, not significant; \*, *P* < 0.05; \*\*, *P* < 0.01; \*\*\*, *P* < 0.001. (Key to abbreviations is given in Table 1.)

Fatty acid	Breed			Sex				Year-born				Sire				
	<sup>3</sup> / <sub>4</sub> J	<sup>3</sup> / <sub>4</sub> LSE		Sig. diff.	Heifer	Steer	SE	Sig. diff.	1996	1997	SE	Sig. diff.	A	B	SE	Sig. diff.
TFA <sup>a</sup>	4544	2010	248	***	3279	3275	255	NS	2929	3625	281	NS	3206	3348	256	NS
MCSFA	838	848	10	NS	843	837	9	NS	832	848	10	NS	826	853	9	NS
LCSFA	456	487	11	**	445	498	10	***	476	467	11	NS	492	451	10	*
OCSFA	35	40	1	***	36	39	1	*	40	35	1	***	39	36	1	**
SATFA	1322	1375	14	**	1324	1374	12	***	1347	1350	13	NS	1357	1340	12	NS
<i>t</i> -MUFA	57	55	3	NS	53	58	2	NS	60	51	3	**	60	52	2	*
<i>c</i> -MUFA	1400	1360	16	*	1402	1357	14	*	1371	1388	15	NS	1364	1394	14	NS
MUFA	1456	1414	14	**	1456	1415	12	*	1431	1439	14	NS	1424	1447	12	NS
n-6 PUFA	78	73	1	NS	76	75	1	NS	80	71	1	***	77	75	1	NS
n-3 PUFA	68	66	1	NS	62	68	1	NS	66	68	1	NS	67	68	1	NS
PUFA	170	163	3	NS	167	167	2	NS	171	163	3	***	168	166	2	NS
n-6:n-3	1.16	1.12	0.01	**	1.15	1.13	0.01	NS	1.22	1.05	0.01	***	1.17	1.11	0.01	***
P:S	0.15	0.17	0.01	NS	0.16	0.16	0.01	NS	0.15	0.16	0.01	NS	0.14	0.17	0.01	**
M:S	1.10	1.00	0.02	***	1.09	1.02	0.02	***	1.05	1.06	0.02	NS	1.04	1.06	0.02	NS
A. index	0.67	0.69	0.01	NS	0.68	0.68	0.01	NS	0.68	0.68	0.01	NS	0.68	0.68	0.01	NS
T. index	1.32	1.36	0.03	NS	1.30	1.37	0.02	*	1.36	1.31	0.03	NS	1.38	1.29	0.02	**

**Table 8** Mean and SE for FA composition (g 100 g<sup>-1</sup> TFA) and desaturation indices for meat from <sup>3</sup>/<sub>4</sub>J and <sup>3</sup>/<sub>4</sub>L heifers and steers born in 1996 or 1997 and sired by Sire A or Sire B in Experiment 2. The covariate used was mg TFA 100 g<sup>-1</sup> raw meat for analyses of FA and desaturation indices in the upper part of the table and the reciprocal of mg TFA 100 g<sup>-1</sup> raw meat for FA in the lower part of the table. NS, not significant; \*, *P* < 0.05; \*\*, *P* < 0.01; \*\*\*, *P* < 0.001. (Key to abbreviations is given in Table 1.)

Fatty acid	Breed				Sex				Year-born				Sire			
	<sup>3</sup> / <sub>4</sub> J	<sup>3</sup> / <sub>4</sub> L	SE	Sig. diff.	Heifer	Steer	SE	Sig. diff.	1996	1997	SE	Sig. diff.	A	B	SE	Sig. diff.
C14:0	2.30	2.20	0.07	NS	2.35	2.14	0.06	**	2.17	2.30	0.07	NS	2.22	2.29	0.06	NS
C15:0	0.34	0.41	0.01	***	0.36	0.39	0.01	NS	0.41	0.34	0.01	***	0.39	0.36	0.01	NS
C16:1	3.60	2.86	0.11	***	3.44	3.03	0.10	**	3.13	3.34	0.11	NS	3.06	3.41	0.10	NS
C17:0	0.75	0.85	0.01	***	0.76	0.84	0.01	***	0.84	0.76	0.01	***	0.85	0.75	0.01	***
C18:0	14.1	15.7	0.3	***	13.9	15.9	0.3	***	15.3	14.5	0.3	NS	15.4	14.4	0.3	*
C18:1 n-9	36.9	35.3	0.4	**	36.6	35.6	0.4	NS	36.0	36.2	0.4	NS	36.3	35.9	0.4	NS
<i>c</i> -C18:1 <sup>1</sup>	2.64	2.43	0.06	*	2.61	2.46	0.05	**	2.55	2.52	0.05	NS	2.53	2.54	0.05	NS
<i>t</i> -C18:1 <sup>2</sup>	0.30	0.33	0.02	NS	0.31	0.31	0.01	NS	0.36	0.27	0.01	***	0.33	0.30	0.01	NS
TVA	1.44	1.35	0.06	NS	1.31	1.47	0.05	*	1.51	1.27	0.05	***	1.50	1.29	0.05	**
CLA	0.38	0.31	0.01	***	0.35	0.33	0.01	NS	0.35	0.33	0.01	NS	0.36	0.32	0.01	*
<i>t</i> -C18:2 n-6	0.36	0.43	0.01	***	0.40	0.41	0.01	NS	0.43	0.37	0.01	***	0.42	0.38	0.01	NS
Desat-C16	0.13	0.11	0.00	***	0.13	0.11	0.00	**	0.12	0.12	0.00	NS	0.11	0.12	0.00	NS
Desat-C18	0.72	0.69	0.01	***	0.72	0.69	0.00	***	0.70	0.71	0.01	NS	0.70	0.71	0.01	NS
Desat-CLA	0.21	0.19	0.01	*	0.21	0.19	0.01	**	0.19	0.21	0.01	**	0.19	0.21	0.01	NS
C18:2 n-6	2.30	2.21	0.04	NS	2.24	2.27	0.04	NS	2.42	2.09	0.04	***	2.29	2.23	0.03	NS
C18:3 n-3	1.33	1.39	0.03	***	1.32	1.39	0.02	NS	1.34	1.38	0.03	NS	1.34	1.38	0.03	NS
C20:3 n-3	0.24	0.22	0.01	NS	0.24	0.23	0.01	NS	0.24	0.22	0.01	***	0.24	0.23	0.01	NS
C22:1 n-9	0.67	0.58	0.02	***	0.64	0.61	0.02	NS	0.59	0.66	0.02	***	0.62	0.63	0.02	NS
AA	0.78	0.68	0.02	**	0.73	0.72	0.02	NS	0.76	0.69	0.02	***	0.76	0.70	0.02	*
EPA	0.19	0.19	0.005	NS	0.19	0.19	0.004	NS	0.18	0.21	0.005	*	0.18	0.20	0.004	*
DPA	0.87	0.81	0.02	*	0.84	0.84	0.02	NS	0.81	0.87	0.02	**	0.83	0.85	0.02	NS
DHA	0.10	0.09	0.005	NS	0.09	0.10	0.005	NS	0.09	0.11	0.004	*	0.10	0.09	0.005	NS

<sup>1</sup>*c*-C18:1 includes *c*-C18:1 n-5, *c*-C18:1 n-6, *c*-C18:1 n-7, and *c*-C18:1 n-8 but excludes *c*-C18:1 n-9.

<sup>2</sup>*t*-C18:1 includes *t*-C18:1 n-8 and *t*-C18:1 n-9 but excludes TVA.



presented in Table 9. CLA was positively correlated with TVA, C18:1 n-9, and C16:1 but negatively correlated to C16:0 and C18:0. Again, there were negative correlations between C17:0 and C14:0, C16:0, C16:1, and C18:1 n-9, and negative correlations between the desaturation indices and C15:0 ( $r = -0.46$  to  $-0.64$ ;  $P < 0.001$ ) and C17:0 ( $r = -0.62$  to  $-0.79$ ;  $P < 0.001$ ). The desaturation indices were again positively correlated with each other ( $r = 0.75$  to  $r = 0.80$ ;  $P < 0.001$ ).

## DISCUSSION

### CLA and TVA in beef

New Zealand all-grass farming systems for finishing beef had no advantage compared with beef finished on feedlots in terms of the proportion or content of CLA and TVA in the beef. Mean proportions of CLA (0.20 and 0.35 g 100 g<sup>-1</sup> TFA) and TVA (1.31 and 1.40 g 100 g<sup>-1</sup> TFA) in both experiments and the mean content of CLA (4 and 11 mg 100 g<sup>-1</sup> raw meat) and TVA (29 and 46 mg 100 g<sup>-1</sup> raw meat) were similar to earlier reports for cattle fed grass, silage, or concentrates (Chin et al. 1992; Malau-Aduli et al. 1997; Enser et al. 1998, 1999; Choi et al. 2000; Mir et al. 2000; Laborde et al. 2001; Scollan et al. 2001). Higher proportions of CLA in beef have been reported by Fogerty et al. (1988) and French et al. (2000) (0.76 and 1.08 g CLA 100 g<sup>-1</sup> TFA, respectively). These differences cannot be explained by the inclusion of different isomers, since all reports were for the *c-9 t-11* isomer of CLA. The content of CLA and TVA increased with increasing content of TFA in both experiments and in Experiment 1 the proportions of these FA also increased with increasing TFA content of the meat. The higher TFA in the raw meat in Experiment 2 largely explains the higher content of CLA and TVA in the beef in Experiment 2 than in Experiment 1.

The high correlations between the CLA and TVA composition and among the desaturation indices in both experiments suggest that TVA may be the main source of CLA in the muscles as well as the mammary gland. At least 78% of the CLA in milk from dairy cows is derived from the conversion of TVA to CLA by delta-9 desaturase (Corl et al. 2001). There were consistent differences in all the desaturation indices among animal types in Experiment 1 and between sexes and breeds in Experiment 2.

The large Adj. CV for CLA and TVA suggest variation in the content of these beef FA that could be exploited by traditional selection, breeding, or management strategies. The question is whether these methods could increase these FA sufficiently to supply enough CLA per serving of beef (i.e., 100 g raw beef) to be nutritionally significant for consumers. The estimated adult daily requirement for CLA to reduce the incidence of breast cancer is 3 g day<sup>-1</sup>. This estimate was based on a 0.1% daily diet of a mixture of CLA isomers reducing the number of mammary tumours in rats by 36% (Ip et al. 1994). However, this mixture of CLA isomers contained only 43% of the *c-9 t-11* CLA isomer, which is suspected to be the active anti-carcinogenic isomer (Lavillonnière & Bougnoux 1999), and a daily intake of 0.05% of the CLA mixture gave a 22% reduction in the number of tumours (Ip et al. 1994). Based on this data, and given the acute treatments used to induce the mammary tumours in these rats, an estimated daily requirement of 750 mg *c-9 t-11* CLA seems reasonable although there would be further reductions in the numbers and incidence of tumours up to a daily intake of about 3750 mg CLA. The mean CLA content of 100 g of lean beef in Experiments 1 and 2 would supply less than 2% of the 750 mg daily requirement, and even the maximum values for CLA would supply only 4–5% of the daily requirement. While the TVA content of beef was up to 7-fold higher than the CLA content and could be considered a precursor of CLA (Corl et al. 2001), the combined mean CLA and TVA content in 100 g of raw beef would still supply only 4–8% of the daily requirement. In contrast, the maximum content for these FA is 3–5-fold greater, supplying about 20% of the daily requirement, which is the minimum content needed to enable beef to be promoted for its CLA content (New Zealand Beef and Lamb Marketing Bureau pers. comm.). Although small increases in the proportions of CLA and TVA could be achieved by selection between and within breeds, and varying traditional management practices, it is unlikely that rapid increases in CLA or TVA of the magnitude required can be obtained by these traditional methods. Feed supplements or manipulation of rumen microflora might be alternative strategies.

### Long-chain PUFA in beef

The content of AA, EPA, DPA, and DHA were similar in both experiments, but the proportions were lower in Experiment 2 than in Experiment 1. The differences can be explained by the mean TFA

content in the meat being higher in Experiment 2 than in Experiment 1 and there was an exponential decrease in the proportions of these FA with increasing TFA. The exponential decrease in the proportions of these PUFA with increasing TFA content of meat occurred because PUFA are concentrated in phospholipids in cell membranes and it is mainly triacylglycerols that increase with increasing TFA content of meat (Itoh et al. 1999; Scollan et al. 2001). In contrast to the proportions, the content of EPA and DPA increased with increasing TFA in both experiments. At similar TFA or lipid content of the meat, the proportions and content of n-3 PUFA and AA in the meat were similar to values found for beef by Shantha et al. (1997) and Enser et al. (1998). Yang et al. (2002) found higher proportions of AA, EPA, and DPA (2.79, 1.27, and 1.84 g 100 g<sup>-1</sup> TFA) in pasture-fed cattle than in these experiments.

There was a high Adj. CV for DHA relative to EPA, DPA, and AA in both experiments but the only factor to have a significant effect on the proportion of DHA was year-born in Experiment 2. This higher proportion of DHA in the meat from cattle born in 1997 than in 1996 was accompanied by higher proportions of EPA and DPA. The three long-chain n-3 PUFA were generally positively correlated to each other and to AA in both experiments. The proportions of AA were also positively correlated to its precursor C18:2 n-9 in both experiments, but C18:3 n-3, the precursor of the long-chain n-3 PUFA, were only positively correlated to EPA in Experiment 2. This was consistent with the suggestion by Gerster (1998) and Sinclair & Li (2000) that C18:3 n-3 was a poor source of long-chain n-3 PUFA in animals.

For a daily adult requirement of EPA and DHA of 350 mg day<sup>-1</sup> (Simopoulos 1996), 100 g of the raw lean beef from these experiments would on average supply about 2% of these FA while the beef with the maximum content of EPA and DHA would supply 4–5%. The content of DPA in beef was more than twice the EPA and DHA content and can be considered a precursor to both (Gerster 1998). Assuming a 100% conversion of DPA to EPA and DHA, then 100 g of lean beef would still only supply 7% of daily requirement using the mean values for these three FA, and 11% if the maximum values were used. Normal breeding and management practices are unlikely to increase the long-chain n-3 PUFA content in 100 g of lean beef sufficiently to provide a nutritionally significant proportion of the daily requirement (i.e., >20%).

### Effects of odd-chain FA

The strong negative correlations between the proportion of C17:0, and to a lesser extent C15:0, in the TFA and the desaturase indices suggest these OCSFA reduced the delta-9 desaturase activity in the muscle. This would explain the negative correlation C17:0 has with C18:1 n-9 and C16:1 and the positive correlation with C18:0. The negative correlation C17:0 has with C16:0 and C14:0 suggests C17:0 may also reduce *de novo* synthesis of FA in the muscle or rumen.

### SATFA, MUFA, and PUFA in beef

The content of SATFA, MUFA, and PUFA in beef and their component groups of FA all increase with increasing TFA content of the meat in both experiments. The proportions of most individual SATFA and MUFA also increased with increasing TFA content of the meat. Exponential decreases in the proportion of the PUFA with increasing TFA content of the meat was indicated by the positive effects of the reciprocal of the TFA content in the meat when included as a covariate in the analyses. Similar relationships between the proportions of individual FA and TFA in the beef were reported by Itoh et al. (1999). The content and proportions of SATFA and MUFA in these experiments were similar to the results of other research with grass-fed beef in which proportions of TFA or lipids were similar (Duckett et al. 1993; Enser et al. 1998; Choi et al. 2000; Yang et al. 2002). In some experiments where concentrates were fed, the proportions of saturated FA were similar to the current experiments (Enser et al. 1998; French et al. 2000) whereas in other experiments they were lower (Mir et al. 2000). The M:S ratio was relatively constant across all experiments, including the present ones, despite differences in feeding regimes and proportions of TFA in the beef; the ratio ranges from 0.84 (Duckett et al. 1993) to 1.15 (French et al. 2000).

In contrast to the content and proportion of SATFA and MUFA, there were large variations in the content and proportion of PUFA among the results from different researchers, especially for the n-6:n-3 ratio. The content and proportions of PUFA in the present experiments were similar to the grass-fed cattle of Enser et al. (1998), but the beef contained lower proportions of C18:2 and higher or similar proportions of C18:3 than in the grass-fed cattle of Duckett et al. (1993) and Yang et al. (2002). These differences could be attributed to differences in the content of fat in the beef and to

the FA content of the lipids in the diets fed to the cattle. In both experiments the Adj. CV for SATFA and MUFA were low while n-6 and n-3 PUFA were moderately high, suggesting that, if heritabilities were equal, there were more opportunities to manipulate the PUFA content of beef by traditional selection and breeding than the SATFA and MUFA content.

### Ratios and indices

The n-6:n-3 ratio of 1.2:1–1.3:1 in Experiments 2 and 1, respectively, were well within the recommended value of <4:1 (Simopoulos 1996; Enser et al. 1998), less than the ratios of 2.3:1–4.2:1 found in some grass-fed beef (Duckett et al. 1993; French et al. 2000), and markedly lower than the ratios of 6.8:1–29.6:1 found in some concentrate-fed cattle (Duckett et al. 1993; Enser et al. 1998; Yang et al. 2002). The P:S ratios (0.16:1–0.33:1) were lower than the recommended value of 0.45:1 (Enser et al. 1998). The A. indices of 0.56–0.69 in the present experiments were less than the values of 0.70–0.72 reported by Ulbricht & Southgate (1991) for lean beef, but the T. indices of 1.07–1.38 were higher than the values of 0.75–1.06 reported by these authors. Both the A. and T. indices in the present experiments were slightly higher than values for poultry (0.5 and 0.95, respectively) and much higher than the values for fish (0.28 and 0.16, respectively) (Ulbricht & Southgate 1991). There are no recommended values for the M:S ratio, but the higher the value the healthier the beef is for humans (Ulbricht & Southgate 1991).

The n-6:n-3 and P:S ratios increased and the A. and T. indices decreased with decreasing fatness of the grass-fed beef in both experiments. At similar fatness, the ST was healthier for the consumer, with a lower n-6:n-3 ratio, and lower A. and T. indices than meat from the other muscles in Experiment 1. The beef from progeny born to Sire B in Experiment 2 was healthier for the consumer than beef from progeny born to Sire A with a lower n-6:n-3 ratio and T. index, and a higher P:S ratio. At a similar fatness the beef from <sup>3</sup>/<sub>4</sub>L had a lower n-6:n-3 ratio and a lower M:S ratio than beef from <sup>3</sup>/<sub>4</sub>J, whereas beef from heifers had a higher M:S ratio and lower T. index than beef from steers. These results suggest that the improvement in the health attributes of beef that influence CHD could be obtained by selection among and within breeds in addition to selecting the muscle or cut of beef and sex of the animal. However, the largest improvement would be obtained by reducing the fat content of beef, which

is a highly heritable trait. This will not only reduce total fat consumption but also improve the health attributes of the fat that is consumed.

### CONCLUSION

In these two experiments large between-animal variations in content of some FA in lean grass-fed beef were observed and it may be possible to manipulate the composition to improve the health image of beef for human consumption, albeit slowly by methods of selection, breeding, and management. Mean CLA plus TVA would need to increase by 3–5-fold and long-chain n-3 PUFA by 2–3-fold in the beef. The larger Adj. CV for PUFA than for SATFA and MUFA suggests that given equal heritabilities, more progress would likely occur by selecting for PUFA than against SATFA.

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