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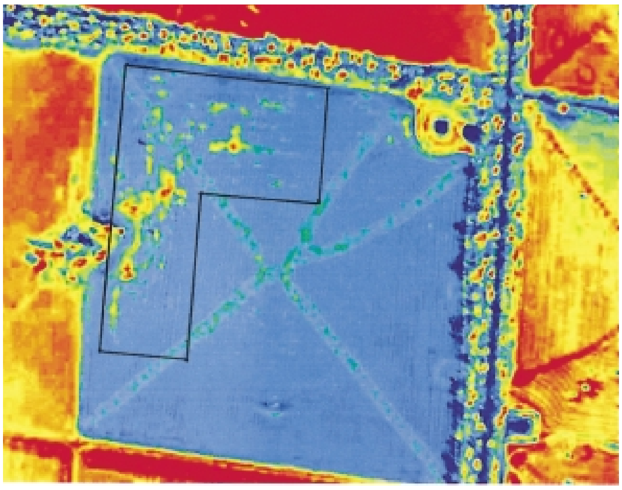

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Environmental effects on the fatty acid composition of subcutaneous beef fat

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Abstract. This paper describes the effect of location and level of nutrition before finishing on the fatty acid composition of subcutaneous beef fat. Interactions between location and nutritional treatments, finishing regime and market category were also examined. The effect of level of nutrition on the fatty acid composition of beef fat during the period from weaning until feedlot entry was small but significant. The lowest level of nutrition had the highest percentage of C18:0 at slaughter, which was offset by reductions in C16:0 in cohort 93-1 and C18:1c9 in cohort 94-2. Location had a large effect on the fatty acid composition of subcutaneous beef fat. At a common slaughter weight, cattle grown in a tropical environment were older, fatter and had higher percentages of saturated fats, including C16:0 and C18:0, than cattle grown out in a temperate environment.

Introduction

Fatty acid composition of beef has received much attention in recent years, a consequence of its perceived implications in human health (Mazier and Jones 1991), beef flavour (Melton 1990) and fat hardness (Davey 1985). Because external fat is increasingly being trimmed from beef before consumption, the reduction in fat intake effectively reduces the impact of variation in fatty acid composition on human health. Fat composition is one of the most variable flavour precursors in beef and although links between fatty acid composition and beef flavour have been established, these effects are not well quantified (Melton 1990). Additionally, differences in flavour detected by trained taste panels in many cases have not been detected by consumer panels (Medeiros *et al.* 1987). Future markets may mature to a stage where fatty acid composition is important. However presently, only the Japanese market discriminates on variation in fatty acid composition as this grading system includes fat softness for its perceived effects on flavour and 'mouth-feel' (Yang *et al*. 1999*a*). In the short term, the industry interest in fatty acid composition of subcutaneous fat is likely to increase because of its effect on fat hardness, which is an important occupational health and safety issue in meat processing plants (Davey 1985).

Many researchers have examined the effect of market weight (e.g. Duckett *et al.* 1993; Camfield *et al.* 1997) and finishing regime (e.g. Mandell *et al.* 1998) on fatty acid composition; although these studies have been restricted to animals raised in 1 environment. We are not aware of studies that have examined the effect of changing nutrition levels during the grow-out period (from weaning to finishing). As changes in nutrition level are common in commercial practice, understanding how they interact with finishing regimes and different market end points is important. The Cooperative Research Centre for Cattle and Beef Quality (CRC) straight-breeding experiment provided an opportunity to quantify the effect of grow-out nutrition, location, finishing regime and market treatments on fatty acid composition of subcutaneous beef fat. As animals bred in the tropics were either finished in the tropics, or transported to a temperate environment for finishing, the straight-breeding experimental design also allowed interactions between location and finishing regime to be examined.

This paper examines the long-term effect of grow-out nutrition on fatty acid composition of subcutaneous beef fat. The effect of environment (location) on fatty acid composition of subcutaneous beef fat and the interactions between location, finishing regime (grain or pasture) and market category (domestic, Korean or Japanese slaughter weights) are examined.

Materials and methods

Fatty acid composition was analysed on subcutaneous fat samples from 577 cattle representing 7 breeds (4 temperate breeds: Angus, Murray Grey, Shorthorn and Hereford, and 2 tropically adapted breeds, Belmont Red and Santa Gertrudis) finished on either pasture or grain to 3 market categories in 2 different locations. The experimental design has been described in more detail by Robinson (1995) and Upton *et al*. (2001).

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Pedigreed calves were purchased by the CRC as autumn (cohort 1), or spring weaners (cohort 2) over 2 years (1993 and 1994). The allocation of animals to treatment groups was balanced for sires within herds and initial liveweight (LW) across treatments. Cattle were allocated to 1 of 3 market categories (domestic 400 kg LW, Korean 520 kg LW and Japanese 640 kg LW) and 2 finish regimes (grain or pasture finished). To reach these market weights, the grain-finished groups were fed for about 60, 100 and 150 days for the domestic, Korean and Japanese groups, respectively. The movement of cattle from background to finishing regimes was based on average liveweight, within a market and finishing group. Tropically adapted cattle were grown out and finished in either the north or the south.

As the design was not fully balanced for grow-out nutrition treatments within sex, or finish within location, subsets of data were extracted from the full CRC dataset for specific comparisons.

Comparison 1. Effect of grow-out nutrition level on fatty acid composition of subcutaneous beef fat

Two cohorts (cohort 93-1 and 94-2) of steers (n = 388) were included in this analysis. During the grow-out period, a nutrition treatment was applied to steers grown out at NSW Agriculture, Glen Innes Research Station. The 3 treatments applied to cohorts weaned in the summer comprised a high nutrition group which grazed improved pasture and a forage crop, a medium nutrition group which grazed improved pasture and supplement pellets and a low nutrition group which grazed only native pasture. These treatments are described in more detail by Oddy *et al.* (1997).

Comparison 2. Effect of grow-out location on fatty acid composition of subcutaneous fat from tropically adapted cattle

Data from only 1 cohort (93-1) of steers (n = 189) was suitable for this analysis. Northern cattle were grown out on pasture at 'Duckponds' Comet, Queensland (24°S, 148°E), and grain finished at a commercial feedlot, 'Goonoo'. Cattle finished in the southern location were allocated to grow-out nutrition treatments as described earlier (comparison 1). Grain finishing in the south was carried out at the Tullimba research feedlot (30°S, 151°E).

Samples collected at slaughter

In comparisons 1 and 2, a 20 g sample of subcutaneous beef fat was collected from a portion (15 cm) of the anterior striploin (*M. longissimus lumborum*) quartered at the 12th/13th rib about 24 h after slaughter and stored at –20°C. Fatty acid composition was analysed by gas-liquid chromatography as described by Smith *et al.* (1998). The raw means of the 15 fatty acids identified are presented in Table 1.

Statistical analyses

As the number of comparisons being evaluated was large, the analysis was limited to the major fatty acids. Of the 15 fatty acids identified by gas-liquid chromatography 6 constituted greater than 2% of the total acids identified (C14:0, C16:0, C16:1c9, C18:0, C18:1c9, and C18:1t11) (Table 1). As C18:2c9,c12 was one of the few fatty acids of purely dietary origin it was included even though it constituted only a small percentage of the total fatty acids (about 1.0%). The 7 fatty acids chosen on average summed to about 93% of all fatty acids extracted from the samples. Before analysis these 7 fatty acids were re-scaled to 100% to prevent variation in the remaining fatty acids contributing to the multivariate analyses.

Analyses were performed using mixed model techniques (ASREML, Gilmour *et al.* 1998). Initially, a multivariate model was used to determine the most appropriate model for all fatty acids. Because the inclusion of all fatty acids would result in a singularity, 1 acid was excluded from the multivariate analysis. As the data had been rescaled to 100%, the excluded fatty acid was implied.

The main effects in the model were finishing regime, market category, breed and herd within breed. Sire within breed and cohort were fitted as random effects. Breed, herd within breed and their interactions were tested for significance using the sire within breed term. All other effects were tested for significance against the error term. Denominator degrees of freedom for the F ratio test were calculated after accounting for the degrees of freedom removed by the sire within breed and the full model. If herd within breed was not significant (P>0.05), it was removed from the model. Similarly non-significant interactions were dropped sequentially until only significant (P<0.05) terms remained in the model. Results from the final multivariate model were used to calculate predicted means, significance of effects included in the model, and for construction of multivariate biplots. Biplots (Gabriel 1971) were considered the most appropriate tool to summarise graphically the multivariate relationships between treatments and individual fatty acids. Biplots are an extension of the conventional principal component (PC) scatter plot where both the treatments and variables are plotted. The graphical presentation illustrates the variation explained by each principal component, the relationship between treatments, between fatty acids, and between treatments and fatty acids.

The final model for the effect of nutrition levels during grow out was:

Fatty acid composition = cohort + finish + market + breed + nutrition + cohort × finish + cohort × nutrition + cohort × finish × market + sire(breed) + error

When performing the multivariate analyses of the effect of location on fatty acid composition with 6 fatty acids (Comparison 2), the model would not converge. Through a process of elimination it was determined that C18:1t11 was responsible for this problem. To complete the multivariate analysis, C18:1t11 was removed and the remaining data re-scaled to 100%. A univariate analysis of C18:1t11 was carried out.

The final model used for the effect of location was:

Fatty acid composition = location + market + finish + breed + market × finish + location × finish + location × market + location × finish × market + sire(breed) + error

Table 1. Raw means for all fatty acids identified, rescaled means and standard deviations for all CRC cattle with percentage fatty acid composition analysed

Fatty acid	Unscaled mean	Rescaled mean	Standard deviation
C14:0	3.54	3.84	0.73
C16:0	27.71	30.01	2.79
C16:1c9	4.18	4.54	1.57
C18:0	13.99	15.13	3.90
C18:1c9	38.59	41.81	4.72
C18:2c9,c12	1.00	1.08	0.46
C18:1t11	3.33	3.61	1.91
C14:1c9	1.05		0.49
C15:0	0.57		0.15
C17:0	1.41		0.45
C17:1	0.93		0.22
C18:1c11	1.47		0.45
C19:0	0.59		0.24
C20/C18:3	0.26		0.15
Conjugated linoleic acid	0.57		0.32

Results

Comparison 1. Effect of level of grow-out nutrition on the fatty acid composition of subcutaneous beef fat

The effect of grow-out nutrition level in the multivariate model was significant, although in the univariate analyses grow-out nutrition was only significant for C16:0 and C18:1c9 (Table 2). The effect of grow-out nutrition level on each individual fatty acid was complicated due to the large number of potential contrasts. A multivariate biplot (Fig. 1) was constructed to summarise the differences between treatments and to examine the relationships between the fatty acids within these treatments. The predicted means were then used to investigate specific comparisons in more detail.

The biplot in Figure 1 summarised the relationships between treatment effects and fatty acid composition. Distances between treatment effects on the biplot correspond with overall differences in fatty acid composition. Grow-out nutrition levels within cohort 93-1 lay in quadrants I and II, and nutrition levels within cohort 94-2 lay in quadrant III and IV. This spatial separation represented graphically the large difference in fatty acid composition between cohorts. The vectors for each fatty acid provide information on both the relationships between fatty acids and between individual fatty acids and treatment effects. As the vector for C18:1c9 projected towards the top of the biplot and grow-out nutrition levels within cohort 93-1 were separated from cohort 94-2 in a similar direction this indicated that C18:1c9 was higher in cohort 93-1, than in cohort 94-2, whilst C16:0, C18:0 and C18:1t11 were lower.

A significant interaction between cohort and grow-out nutrition level was observed (Table 2) and this was represented in Figure 1. Within cohort 93-1, the high nutrition group was separated from the low and medium groups, which were similar. The separation was towards the right of quadrant II, indicating that the high nutrition group had the largest percentages of C16:0, C16:1c9, and C14:0, but lower percentages of C18:0 and C18:1t11. In cohort 94-2, the grow-out nutrition treatments were graded from high to low moving from left to right and towards quadrant II of the biplot. This indicated that as the level of grow-out nutrition increased, the percentages of C14:0, C16:1c9, C18:1c9 and C18:2c9,c12 increased, at the expense of C18:0 and C18:1t11, while C16:0 was unchanged.

In cohort 93-1, the high grow-out nutrition group expressed a lower percentage of C14:0 (–0.3%), C16:0 (–1.1%), C16:1c9 (–0.7%) and C18:1c9 (–0.7%) than the low and medium groups, which were similar (Table 3). The reverse was true for levels of C18:0 (1.4%) and C18:1t11 (0.5%). Within cohort 93-1, C18:2c9,c12 was not affected by grow-out nutrition level.

In cohort 94-2, nutrition level during growout was shown to affect percentages of C14:0, C16:0, C18:1t11 and C18:2c9c12. As the grow-out nutrition level increased, the percentage of C18:1c9 (1.4%) and C16:1c9 (0.6%) increased, while C18:0 (–2.0%) and C18:2c9,c12 (–0.03%) decreased.

The multivariate analysis showed that the interaction of finishing regime, market category and cohort was significant

Table 2. Sources of variation in model describing the effect of growout nutrition level, finishing regime and market category on fatty acid composition of subcutaneous fat of steers grown in a temperate environment

NDF, numerator degrees of freedom; DDF, denominator degrees of freedom

Treatment	NDF	DDF	*F*	*P*-value
Cohort × nutrition	12	2016	3.16	**
C14:0	2	336	2.91	n.s.
C16:0	2	336	5.33	**
C16:1c9	2	336	1.61	n.s.
C18:0	2	336	0.92	n.s.
C18:1c9	2	336	11.30	***
C18:1t11	2	336	2.15	n.s.
C18:2c9,c12	2	336	0.08	n.s.
Cohort × finish × market	18	2016	36.72	***
C14:0	3	336	54.91	***
C16:0	3	336	8.44	***
C16:1c9	3	336	37.04	***
C18:0	3	336	34.62	***
C18:1c9	3	336	26.77	***
C18:1t11	3	336	7.32	***
C18:2c9,c12	3	336	58.32	***
Nutrition	12	2016	4.81	***
Breed	18	216	9.34	***
Market	12	2016	14.51	***
Finish	6	2016	46.05	***
Cohort	6	2016	58.86	***

**P*<0.05; ***P*<0.01; ****P*<0.001; n.s., not significant.

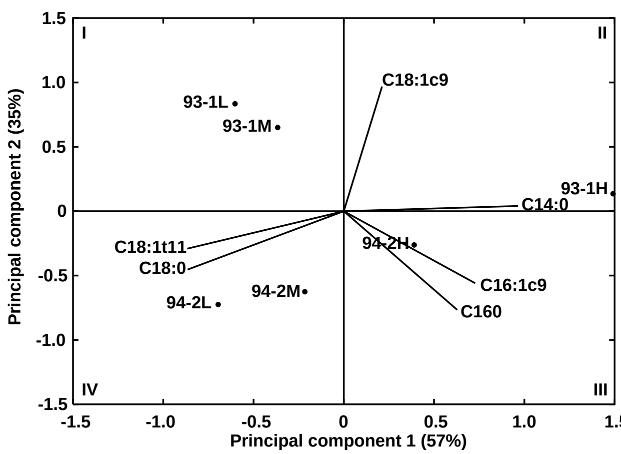

Figure 1. Biplot illustrating the effect of cohort and grow-out nutrition level (H, high; M, medium; L, low) on fatty acid composition of subcutaneous fat of steers grown in a temperate environment.

Table 3. Predicted means for growout nutrition levels and cohort effects on the percentages of fatty acids in subcutaneous fat of steers

Nutrition	C14:0	C16:0	C16:1c9	C18:0	C18:1c9	C18:1t11	C18:2c9,c12
			Cohort 93-1				
High	4.0	31.6	5.1	14.4	43.9	2.8	1.01
Medium	3.8	30.8	4.4	15.7	44.3	3.2	1.03
Low	3.7	30.5	4.4	15.8	44.6	3.3	1.04
			Cohort 94-2				
High	3.7	32.1	5.1	16.3	41.9	3.4	0.92
Medium	3.7	32.3	4.7	17.5	40.8	3.5	0.96
Low	3.5	32.2	4.5	18.3	40.5	3.4	0.95
Maximum s.e.	0.08	0.24	0.12	0.33	0.35	0.14	0.02

(Table 2 and Fig. 2). This was also reflected in the significance of the univariate analyses for all fatty acids. Most grain-finished groups were located in quadrant III and IV of Figure 2, while pasture groups were in quadrant I and

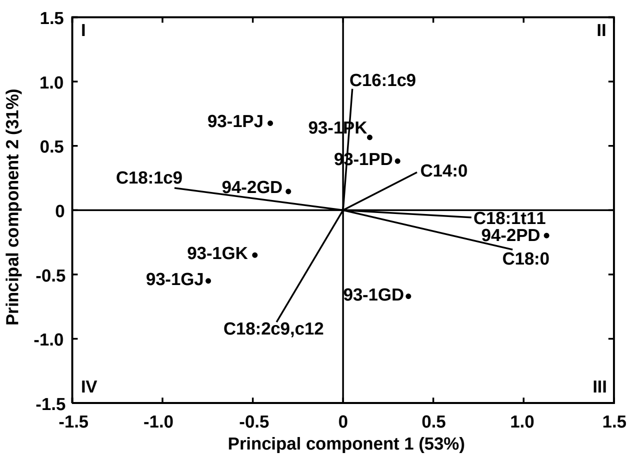

Figure 2. Biplot illustrating the effect of cohort, market category (D, domestic; K, Korean; J, Japanese) and finishing regime (G, grain; P, pasture) on fatty acid composition of subcutaneous fat in steers grown out in a temperate environment.

II. Thus, the major fatty acid explaining variation in this direction was C18:2c9,c12, indicating that grain-finished cattle were higher in C18:2c9,c12, and this increase was offset by reduced levels of C16:1c9. Within all market and cohort categories pasture-finished cattle were to the right of grain-finished cattle on the biplot (Fig. 2). This indicated that, generally, pasture-finished cattle were higher in C14:0, C16:0, C18:0 and C18:1t11, at the expense of C18:1c9, than grain-finished cattle. Additionally, within a cohort and finishing regime, heavier target market weights generally lay to the left of the biplot, which indicated that as market weight increased, so too did C18:1c9 at the expense of C14:0, C16:0 C18:0 and C18:1t11.

The predicted means presented in Table 4 showed that the percentage of C18:2c9,c12 was higher in all grain-finished groups, compared with their pasture-finished counterparts. This increase ranged from 0.4 to 0.7%, which, although small, represented, on average, a 45% change in the percentage of this fatty acid. C16:1c9 increased (0.9–1.6%) in all pasture-fed groups, except the 94-2 domestic market group. C18:0 was similar in all groups except the 94-2 domestic market group, in which the grain-finished group was 5.8% lower. C18:1c9 was similar, or higher, in all

Table 4. Predicted means for cohort, finishing regime and market category effects in temperate steers on the percentage fatty acids composition in subcutaneous fat

Finish	Market	C14:0	C16:0	C16:1c9	C18:0	C18:1c9	C18:1t11	C18:2c9,c12
				Cohort 93-1				
Grain	Domestic	4.2	32.2	3.9	17.6	40.6	3.3	1.4
	Korean	3.6	31.1	4.2	15.1	45.0	2.6	1.1
	Japanese	3.2	30.3	4.1	14.0	47.1	3.2	1.3
Pasture	Domestic	4.2	30.5	4.8	16.6	43.2	3.0	0.7
	Korean	3.9	31.8	5.2	15.3	43.1	3.2	0.7
	Japanese	3.7	30.0	5.7	13.3	46.5	3.3	0.9
				Cohort 94-2				
Grain	Domestic	3.7	32.8	4.8	14.5	43.2	2.6	1.0
Pasture	Domestic	3.5	31.7	4.7	20.3	38.9	4.3	0.9
Maximum s.e.		0.11	0.33	0.17	0.47	0.49	0.19	0.03

grain (0.6–4.3%) compared with pasture-finished groups, except cohort 93-1 domestic market cattle, in which the grain-finished groups were lower (–2.6%).

As market weight increased from the domestic to Japanese groups, C18:0 and C14:0 decreased (–3.1 to –3.6% and –0.5 to –1.0% respectively) while C18:1c9 increased (3.3 to 6.5%). C16:1c9 (maximum change 0.9%) either remained the same, or increased slightly in response to increasing market weight.

Comparison 2. Effect of location on fatty acid composition of subcutaneous fat from tropically adapted cattle

For comparison 2 the interaction of location, finishing regime and market category was significant in the multivariate model. Generally this was reflected in the univariate analyses although C14:0, C16:1c9 and C18:1c9 were not significant (Table 5).

Fatty acid composition differences between location, finishing and market are summarised in Figure 3. Generally, cattle grown out in the south lay to the right (quadrants II and III) of cattle finished in the north (quadrants I and IV) within the same market category and finishing regime in the biplot. This indicated that southern cattle were higher in C18:1c9 and lower in C18:0 than their contemporaries grown out in the north. It appeared that this reduction in C18:1c9 was offset in the northern pasture-finished domestic and Japanese market groups by a concomitant increase in C16:0. These groups were located above their southern contemporaries in the biplot (Fig. 3). As C16:0 extended into quadrant I, this suggested that the reduction in C18:1c9 in these groups was offset by the increased percentages of C16:0. Furthermore, northern grain-finished domestic and Korean market cattle lay to the left and below their southern counterparts in the biplot (Fig. 3). This indicated that northern grain-finished cattle were higher in C18:2c9,c12 than their southern counterparts.

Generally, within a target market weight and location, grain-finished cattle were to the right of pasture-finished cattle in the biplot in Figure 3. Where the grain-finished groups were below and to the right of pasture-fed groups (as in the northern and southern domestic market treatment groups), the grain-finished groups were higher in C18:1c9 and lower in C16:0 and C18:0. Where the grain-finished cattle were located below the pasture-finished cattle in Figure 3 (Korean north, Korean south and Japanese south market groups), the increase in C18:1c9 was offset by decreased percentages of C16:0. Within the southern Japanese market treatment group, the grain and pasture-finished cattle had similar percentages of C18:1c9, while grain-finished cattle had lower percentages of C16:0.

The biplot in Figure 3 showed that Japanese market cattle (within a location and finishing category) were consistently located to the right of Korean cattle, which in turn, were to the right of domestic cattle. The projection of C16:1c9 and C18:1c9 into quadrants II and III respectively indicated that the percentages of these fatty acids increased according to market weight. Further, the projection of C16:0 and C18:0 in the opposite direction indicated that this increase was offset by reductions in C16:0 and C18:0.

Table 6 showed the predicted means for the interaction between finishing regime, market category and grow-out location for individual fatty acids. Some fatty acids, particularly C18:0, were strongly affected by these factors. Northern grain-finished cattle had much higher percentages of C18:1t11 than all other groups. Furthermore, southern pasture-finished domestic market cattle had higher levels of

Table 5. Sources of variation from a model describing the effect of grow-out location, finishing regime and market category on fatty acid composition of subcutaneous fat of tropically adapted steers

NDF, numerator degrees of freedom; DDF, denominator degrees of freedom

Effect	NDF	DDF	*F*	*P*-value
Location × finish × market	5	775	4.15	**
C14:0	1	155	0.21	n.s.
C16:0	1	155	6.52	*
C16:1c9	1	155	0.91	n.s.
C18:0	1	155	7.29	**
C18:1c9	1	155	0.30	n.s.
C18:2c9,c12	1	155	12.46	***
Location × market	10	775	8.19	***
Location × finish	5	775	8.44	***
Market × finish	10	775	4.75	***
Breed	5	110	12.92	***
Finish	5	775	17.81	***
Market	10	775	8.46	***
Location	5	775	5.05	***

*$P<0.05$; **$P<0.01$; ***$P<0.001$; n.s., not significant.

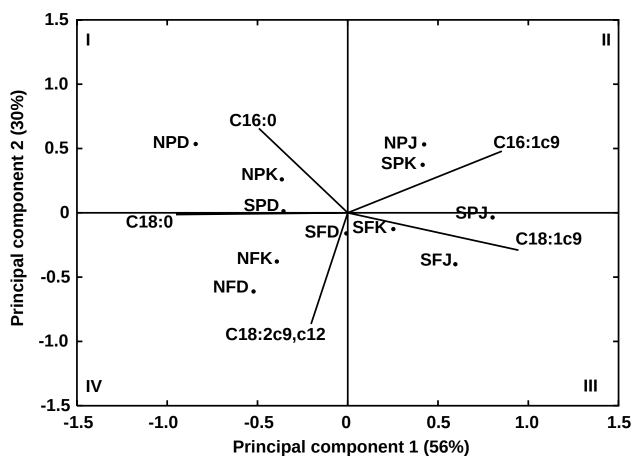

Figure 3. Biplot illustrating the effect of grow-out location (N, north; S, south), finishing regime (G, grain; P, pasture) and market category (D, domestic; K, Korean; J, Japanese) on the fatty acid composition of subcutaneous fat in tropically adapted steers.

Table 6. Predicted means for finish, market and location effects on subcutaneous fat of tropically adapted steers

Market	Location	C14:0	C16:0	C16:1c	C18:0	C18:1c9	C18:1t11	C18:2c9,c12
				Grain finish				
Domestic	North	4.1	29.3	3.0	17.5	36.8	7.3	2.0
	South	3.9	30.5	4.0	15.5	42.4	2.5	1.0
Korean	North	4.0	29.5	2.6	16.0	37.3	8.9	1.5
	South	3.8	30.5	5.1	12.6	42.9	3.7	1.2
Japanese	South	3.7	28.9	5.5	11.5	46.1	2.9	1.2
				Pasture finish				
Domestic	North	4.1	33.1	3.9	21.4	33.4	3.4	0.6
	South	3.9	28.9	3.8	20.4	37.4	4.8	0.6
Korean	North	4.0	31.3	4.3	18.7	37.5	3.5	0.6
	South	4.2	31.8	6.7	11.2	42.7	2.7	0.7
Japanese	North	3.9	32.6	7.0	10.9	42.6	2.2	0.6
	South	3.8	29.2	7.0	10.6	45.9	2.7	0.8
Maximum s.e.		0.25	0.84	0.46	1.05	1.23	0.39	0.07

C18:1t11 than northern pasture-finished and southern grain-finished domestic market cattle. The reverse occurred in the Korean market weight category, in which there was no difference between these animals and Japanese market grain- and pasture-finished cattle.

In agreement with the biplots, the predicted means presented in Table 6 showed that within all finish-market groups, southern cattle were higher in C18:1c9 (3.6 to 5%) and lower in C18:0 (0 to 7.8%), or C16:0 (0 to 3.3%) than northern cattle. Within the grain-finished, domestic and Korean market categories, northern animals were also higher in C14:0. C16:0 was higher in northern pasture-finished domestic, pasture-finished Japanese and grain-finished Korean market cattle, but similar in the remaining groups. Southern grain-finished domestic, Korean and pasture-finished Korean market cattle were lower in C16:1c9 than their northern counterparts and similar in remaining groups. In comparison to southern grain-finished cattle, C18:2c9,c12 was higher in all northern grain-finished cattle. Northern and southern pasture-finished cattle were similar in C18:2c9,c12.

Discussion

Both grow-out nutrition level and location significantly affected the fatty acid composition of subcutaneous beef fat at slaughter, although nutrition level resulted in only minor differences. There were large differences between cohorts in fatty acid composition, although these differences were confounded with breed, property of origin, birth year and pre-weaning nutrition and therefore difficult to interpret. Further, the effect of market category and finishing regime within these treatments generally agreed with previous descriptions of the effects of increasing age and fatness on fatty acid composition.

Few studies have examined the effect of changes in grow-out nutrition on fatty acid composition of fat in cattle. Hornick *et al.* (1998) manipulated growth rates during growout through increases in stocking rate, while slaughtering at a constant fat depth to remove differences in fatness. These researchers found no difference in fatty acid composition of subcutaneous fat resulting from manipulation of growth rate. The growth rates, weight and fatness of the cattle used in this CRC experiment have been described previously by Oddy *et al.* (1997), who found that increases in grow-out nutrition levels resulted in increased fatness at slaughter. Many studies have shown that increasing weight and fatness can lead to increases in C18:1c9 at the expense of C18:0 (e.g. Mandell *et al.* 1997). It is likely that the changes in fatty acid composition observed in this study may reflect in part differences in fatness between these groups.

The effect of location and finishing regime on fatty acid composition of subcutaneous fat has 2 main features: (i) in the northern grain-finished cattle, fatty acid composition of subcutaneous beef fat was vastly different from northern pasture-finished cattle and both southern finishing groups, and (ii) the comparison between pasture finishing in tropical and temperate environments. Many factors may be involved in the observed differences in fatty acid composition between cattle grown out in the tropical (northern) and temperate (southern) environments including diet, season, ambient temperature and growth path.

The percentages of C18:1t11 in northern grain-finished cattle were much higher than that of southern grain-finished cattle. Although there are few reports (Leth *et al.* 1998; O’Kelly and Speirs 1993) on the percentages of C18:1t11 in subcutaneous fat in the literature, the observed levels of these acids in the northern grain-finished cattle (9.3 and 8.9%) were relatively high in comparison. High levels of C18:1t11 have previously been reported as a result of inclusion of vegetable oils in the diet. O'Kelly and Speirs (1993) found that feeding safflower oil could dramatically increase the amount of

C18:1t11 (8.9%) in adipose tissue, while C18:2c9,c12 remained unchanged. Additionally, the level of C18:2c9,c12 in subcutaneous fat has been found to be dependent on the level of protection of unsaturated vegetable oils from hydrogenation by rumen bacteria. The results of such protection have been highly variable. A number of researchers have found large changes in fatty acid composition (e.g. Scott and Ashes 1993) while other studies reported little or no change in fatty acid composition (e.g. St. John *et al.* 1987; Rule *et al.* 1994; Mandell *et al.* 1997).

The only possible source of such protected fat in the northern ration was cottonseed, which accounted for about half the total fat in the ration. The effect of cottonseed on fatty acid composition was equivocal due to its high level of fat (20–23%, of which 60% was C18:2c9,c12) and its content of cyclopropene fatty acids. Cyclopropene fatty acids have been shown to inhibit the activity of the desaturase enzymes resulting in increased percentages of saturated fatty acids in fat (Raju and Reiser 1967; Cook *et al.* 1976; Yang *et al.* 1999*b*). Although the inclusion of cottonseed in the ration was most likely the cause of the observed differences in fatty acid composition between the northern and southern grain-finishing groups the confounding of ration with grow-out location precluded this conclusion.

Generally cattle finished in the north tended to have more saturated subcutaneous fat with more C18:0 and C16:0 and lower C18:1c9 than cattle finished within the same finishing regime and to the same market weight in the south. Although the comparison is confounded it is possible that at least part of this effect may be attributed to differences in ambient temperature. There was a 9°C difference in average ambient temperature between Armidale (southern growout) and Emerald (northern growout) (Clewett *et al.* 1994). Lefaucheur *et al.* (1991) found that pigs grown out at 12°C had much higher percentages of unsaturated fatty acids in their subcutaneous fat than pigs grown out at 28°C. Accordingly, Perry *et al.* (1998) found that cattle grown out at lower temperatures had increased C18:1c9 deposited in subcutaneous fat and they hypothesised that these differences may have been associated with the temperature differential between the locations.

Slaughter date of some north and south comparisons (within a finish and market) was confounded by season. For example, the northern and southern grain-finished Korean market cattle were slaughtered 6 months apart. Seasonal oscillations in fatty acid composition do occur (Kelly *et al.* 1999). The percentage of C18:0 was highest in late autumn, whilst C16:1c9 and C18:1c9 were highest in late spring. The maximum magnitude of seasonal variation in fatty acid composition was 2.76% for C18:0 in pasture-fed cattle (Kelly *et al.* 1999). This seasonal effect could have contributed to the observed differences in C18:0 and C18:1c9 between the northern and southern grain-finished Korean market cattle. However, the magnitude of the difference in fatty acid composition between northern and southern finished cattle was much larger than that attributable to season alone.

At slaughter, northern animals were older and fatter than their southern counterparts, and their fat contained more C18:0 and less C18:1c9. In contrast, it is generally expected that as cattle age and deposit fat, subcutaneous fat becomes more unsaturated (e.g. Mandell *et al.* 1997). The substantial differences in growth path and age between northern and southern cattle in this study may have contributed to the observed changes in fatty acid composition. In the north, slower overall growth rates were observed, including a 6-month period in which little growth occurred (Oddy *et al.* 1997). It was possible that fatty acid synthesis and lipolysis rates of cattle considered in this study were altered by the harsh restriction imposed post-weaning. Pothoven *et al.* (1975) found that cattle with restricted growth rates, when analysed at the same fatness, exhibited a reduced capacity for fatty acid synthesis and lipolysis. Hence differences in growth path cannot be ruled out as a cause of the observed differences in fatty acid composition between northern and southern finished cattle.

Within both comparisons 1 and 2, the effect of increasing market weight resulted in consistent changes in fatty acid composition. When market weight was examined within finishing regime and cohort (Comparison 1), or grow-out location and finishing regime (Comparison 2), heavier market weight cattle had increased percentages of C16:1c9 and C18:1c9 while lower in C14:0, C16:0, C18:0 and C18:1t11. Heavier carcass weights tended to produce higher percentages of C18:1c9 and lower percentages of C18:0 and this is consistent with the reports of Dinius and Cross (1978), and Xie *et al.* (1996). Additionally, C18:1c9 has been shown to increase with age and fatness in intramuscular *M. longissimus dorsi* fat by Mills *et al.* (1992), Camfield *et al.* (1997) and Xie *et al.* (1996). However, the relationships between days on grain and fatty acid composition are less clear.

Although a large interaction between grain finishing and northern growout was observed in which C18:1t11 and C18:2c9,c12 were much higher in northern grain-finished groups than all other groups, grain finishing generally increased C18:1c9 at the expense of C16:0 and/or C18:0. This is in agreement with previous studies which reported that grain finishing increased the percentages of C18:1c9 in subcutaneous (e.g. Melton *et al.* 1982) and intramuscular fat depots (e.g. Mandell *et al.* 1997, 1998). Also concurring with the present study are reports that C18:2c9,c12 increases in response to grain finishing (e.g. Melton *et al.* 1982; Mandell *et al.* 1998). Increases in C18:2c9,c12 were also observed in southern finished cattle, albeit not as dramatic.

The implications of changes in fatty acid composition on fat hardness are complex and unfortunately fat hardness was not measured in this experiment. However, in an attempt to quantify the impact of these changes on fat hardness, a prediction equation was derived from a data set of 80 subcutaneous fat samples in which both fatty acid composition and slip point were measured (Perry *et al.* 1998). In this dataset cattle were finished in 2 locations and the fatty acid composition covered a similar range of fatty acid percentages to the current study (Slip points ranged from 26 to 45°C; C18:0 7 to 23%; C18:1c9 34 to 54%, Perry *et al.* 1999). The regression equation to predict slip point from fatty acid composition, as expected, had a high coefficient of determination ($R^2 = 0.86$). Within the cohorts in Comparison 1, there was little difference in predicted slip point (cohort 93-1<1°C, 94-1<2°C, compared with cohort 942). This suggested that the small changes in fatty acid composition due to different nutrition levels imposed during growout also had little effect on fat hardness. However there was substantial variation (up to 7°C) in the predicted values of melting points for the interaction of cohort, market end point and finishing regime in Comparison 1. The domestic market groups had the highest predicted slip point, except domestic grain-finished 94-1 cattle, which had intermediate predicted slip points. Additionally, pasture-finished cattle generally had higher predicted slip points than the equivalent pasture-finished groups, except 94-1 domestic, 93-1 domestic and 93-1 Japanese market groups, where the predicted slip points were similar (<1.6°C). These predictions inferred that pasture-finished cattle would have harder fat and as market weight increases, fat hardness would decrease.

In Comparison 2, pasture-finished cattle again had higher predicted slip points than cattle within the same market category and grow-out location, except for southern Korean groups that were the same. As target market weight increased, the predicted slip point decreased in all contrasts. The cattle grown out in the north had higher predicted slip points than similar markets endpoint groups and finishing regimes in the south. This difference was particularly evident in the pasture Korean contrast, where the predicted slip point was 6.8°C higher for northern cattle.

Conclusion

The study has demonstrated that differences in nutrition level during grow-out nutrition levels had a minor affect on fatty acid composition of subcutaneous beef fat at slaughter. However, it cannot be determined if differences would be maintained if finished to the same level of fatness, or for a longer period. Grain feeding increased the percentages of C18:1c9 and C18:2c9,c12 at the expense of C16:0 and C18:0. Increasing market weights resulted in increases in C16:1c9 and C18:1c9 at the expense of C14:0, C16:0, C18:0 and C18:1t11.

Cattle slaughtered at the same weight in the north were much older, fatter, and had a vastly different fatty acid composition of subcutaneous fat. These differences in fatty acid composition, however, were the opposite of that expected from animals of increased age and fatness, in that the northern finished animals produced subcutaneous fat that was higher in C18:0 and C16:1c9 and lower in C18:1c9 than their southern counterparts. Finishing on grain increased the percentage of C18:1c9 at the expense of C18:0. As the market weight increased the percentage of C18:0 decreased while C18:1c9 and C16:1c9 increased.

The changes in fatty acid composition from both Comparisons 1 and 2 suggested that grain finishing should result in softer fat and that increasing market weight should lead to softer fat. Additionally, the predictions showed that the differences in fatty acid composition due to the nutrition treatments during growout had little effect on fat hardness. Cattle finished in tropical environments had harder fat than similar cattle finished in the temperate environments.

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