Original Article

Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and *trans* fatty acids in Australian beef cuts: potential impact on human health

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The influence of feeding systems on the levels of functional lipids and other fatty acid concentrations in Australian beef was examined. Rump, strip loin and blade cuts obtained from grass feeding, short-term grain feeding (80 days; STGF) and long-term grain feedlot rations (150-200 days; LTFL) were used in the present study. The typical Australian feedlot ration contains more than 50% barley and/or sorghum and balanced with whole cottonseed and protein meals were used as feed for STGF and LTFL regimens. Meat cuts from 18 cattle for each feeding regimen were trimmed of visible fat and connective tissue and then minced (300 g lean beef); replicate samples of 7g were used for fatty acid (FA) analysis. There was a significantly higher level of total omega-3 (n-3) and long chain n-3 FA in grass-fed beef (P <0.0001) than the grain-fed groups regardless of cut types. Cuts from STGF beef had significantly reduced levels of n-3 FA and conjugated linoleic acid (CLA) and similar levels of saturated, monounsaturated and n-6 FA compared with grass feeding (P <0.001). Cuts from LTFL beef had higher levels of saturated, monounsaturated, n-6 FA and *trans* 18:1 than similar cuts from the other two groups (P <0.01), indicating that increased length of grain feeding was associated with more fat deposited in the carcass. There was a step-wise increase in *trans* 18:1 content from grass to STGF to LTGF, suggesting grain feeding elevates *trans* FA in beef, probably because of increased intake of 18:2n-6. Only grass-fed beef reached the target of more than 30mg of long chain n-3 FA/100 g muscle as recommended by Food Standard Australia and New Zealand for a food to be considered a source of omega- 3 fatty acids. The proportions of *trans* 18:1 and n-6 FA were higher (P<0.001) for both grain-fed beef groups than grass-fed beef. Data from the present study show that grain feeding decreases functional lipid components (long chain n-3 FA and CLA) in Australian beef regardless of meat cuts, while increasing total *trans* 18:1 and saturated FA levels.

Key Words: grain feeding, beef cattle, omega -3 (n-3) fatty acids, trans fatty acids, functional fats

Introduction

In recent years there has been a greater demand for foods with increased levels of functional fatty acids, such as long-chain omega-3 fatty acids and conjugated linoleic acids, because of their biological roles in cells. For these reasons, the advisory panel of the World Review of Nutrition and Dietetics[1] urged producers to improve the lipid profile of foods of animal origin through optimal feeding systems, as animal foods are still a major source of lipid for humans. These health professionals stressed the importance of increasing the functional lipid components in meat and egg products, while reducing the levels of saturated and *trans* fatty acids and cholesterol.

Higher intakes of long chain omega-3 fatty acids in the diet have been reported to improve the functions of immune, nervous, and cardiovascular systems in humans,[2-4] and the reproductive performance and carcass quality in ruminants.[5-9] Similarly, there is an increasing interest in conjugated linoleic acid (CLA) from ruminant milk and meat because of the potential benefits for human health.[10-12]

Advances in agricultural technology with increased use of grains and formulated feedlot rations in animal feeding systems has resulted in changing levels of functional lipids, saturated and *trans* fatty acid content in farm animals. This, in turn, can alter the carcass components and product quality or nutritive value of the meat. Under Australian feeding systems, due to fluctuation in climatic conditions, the quality of pasture varies throughout the year.

The majority of Australian beef and lamb are grass fed, but during dry seasons may be grain fed. In addition, there is increased emphasis in Australia for the feedlotting of cattle and the length of time that animals are grain fed in a feedlot will depend on seasonal conditions and the target market weight required. In recent years there has been a shortage of quality pasture and the proportion of beef cattle raised on feedlot rations in Australia has in-creased and 35-40% of cattle destined for the domestic market are under

lot feeding.[13] This may have lead to changes in functional lipid components and other fatty acids in red meat from typical beef produced from pasture feeding.

To evaluate the fatty acid nutritive value of beef produced from different feeding regimens in Australia, we investigated the functional and other important fatty acid concentrations in beef cuts of cattle maintained under Australian feeding systems i.e, grass-fed, short term grain-fed (STGF) or long term grain-fed (LTFL) provided as feedlot rations.

Materials and methods
Animals and diets
Beef samples for this study were collected from cattle raised in southern Queensland, and central and northern New South Wales (NSW) of Australia. Cattle were predominately Hereford and Shorthorn with some Angus cross and all of the *Bos taurus* breed. Cattle were raised under grazing temperate grasses. Some animals remained on grass until slaughter (grass fed), while others were fed a feedlot ration for 80 days (short term grain feeding) or 150-200 days (long-term grain feeding). Cattle from all three groups were slaughtered at the same age i.e., at 18 months of age. The feedlot ration that was fed to cattle was a typical Australian typical feedlot ration formulated with more than 50% of barley and/or sorghum and balanced with whole cotton seed plus protein meal (cotton seed meal). The ration, which was offered ad libitum, contained 110-120g crude protein (CP) and 11.5MJ metabolisable energy (ME) per kg dry matter.

Muscle sample description
Muscle samples from cattle fed on temperate grass were sourced from northern and central NSW and grain-fed cattle were from feedlots in southern Queensland. Cattle were slaughtered at 18 months of age in commercial abattoirs and the samples were collected as rump, strip loin and blade cuts for the analysis of fatty acid concentrations. Upon collection at the abattoir, cuts (approx. 300g) were frozen at -20°C and sent to the Department of Food Science, RMIT University, Melbourne, Victoria. Within a month of arrival, cuts stored at -20°C were trimmed of external fat (subcutaneous fat and connective tissues) and the rest (lean meat) was minced immediately using a food processor (Sunbeam OSKAR II, Australia) and maintained at -20°C until further analysis for total fatty acid levels. In each dietary regimens, there were 3 groups of 6 animals (18 cattle), each group being from a separate property, and 3 meat cuts (rump, strip loin and blade) per animal.

Analysis of fatty acid levels
Lipid extractions and fatty acid analyses of meat samples were carried out in duplicate. Approximately 7g portions of minced homogenized sample were extracted with 60 mL of chloroform-methanol (2:1 v/v) containing 10mg/L of butylated hydroxytoluene and 5mg of methyl tricosanoate as internal standard (C23:0, Nu-Chek-Prep, Elysian, MN, USA). Following extraction overnight and filtering, and 8mL aliquot of the filtrate was mixed with 2mL of 0.9% NaCl, shaken and left overnight at 4°C to remove aqueous impurities. On the following day, the lower phase containing lipids was evaporated with pure nitrogen gas and fatty acids methyl esters (FAME) of the total lipids were prepared by the addition of 1mL of toluene and 3mL of 0.9 M H_2SO_4 in methanol and heating the resulting solution at 70°C for 2h with shaking at 15 min intervals. Upon cooling, 3mL of petroleum ether and 3mL of distilled water was added. This mixture was then thoroughly mixed and centrifuged for 10min at 1000 rpm. The fatty acid containing upper phase was separated in a screw-capped tube, evaporated to dryness and reconstituted with petroleum ether. The fatty acid methyl esters were separated by capillary gas liquid chromatography[14] using a 60m x 0.32mm fused silica bonded phase column (BPX70, SGE, Melbourne, Australia). Fatty acids were identified by comparison with standard mixtures of FAME (Nu-Chek-Prep, Elysian, MN, USA), and the results were calculated using response factors derived from chromatographing standards of known composition.

Statistical Analysis
Data were analyzed using the Minitab Statistical Software (MINITAB release 13.32 for windows, MINITAB INC 2000). Results of individual and total fatty acids between dietary regimens and cuts were analyzed by ANOVA using the general linear model procedure. When tested as 3 x 3 factorial design (3 dietary regimens and 3 beef cuts), there was no significant interactions observed, therefore results are presented as means and SEM between dietary regimens. The main effect tested was dietary treatments in order to understand the influence of feeding systems on fatty acid concentrations. In each treatment, 18 observations of beef samples were included in the statistical analysis. When significant treatment effects were detected by ANOVA, means were separated using least significant difference with $P<0.05$ considered statistically significant.[15]

Results
In the present study, only fatty acids of C14 and above were reported, as they are the predominant fatty acids in beef. When analysed as 3 x 3 factorials, none of the individual or total FA concentrations reported showed significant interaction (diet x meat cuts, $P>0.05$). Therefore, treatment effects on FA concentrations of cuts only are discussed in this study. Fatty acid composition of diets was not reported as no feed samples were collected at the time of feeding. However, from the dietary ingredients used for feed formulation, the FA composition of diets could be closely identified from other reported publications.[16,17]

Dietary treatment had similar effect on the concentrations of 18:0, 18:1cis-9, CLA, 18:2n-6 and 18:3n-3 between cuts (Table 1). Meat samples from cattle fed grass and STGF had significantly lower levels of 18:0 and 18:1cis-9 compared with cattle fed LTFL. In all three cuts, CLA concentration was approximately 2-fold higher with grass and LTFL than STGF feeding. The concentration of 18:2n-6 FA was lowest for grass fed animals and highest for LTFL animals. With grass feeding, there was a two-fold higher level in 18:3n-3 concentration compared with beef from cattle fed STGF and LTFL

Table 1. Effect of grass, short-term and long-term grain feeding on myristic, palmitic and C18 fatty acid concentrations of rump, strip loin and blade cuts[1]

	14:0	16:0	18:0	18:1-cis9	18:1-*trans*	CLA[2]	18:2n-6	18:3n-3
			Fatty acid concentration (mg/100 g lean meat)					
Rump cuts								
Grass	74.6	588[a]	361[a]	1050[a]	63.3[a]	31.5[b]	190.4[a]	48.9[b]
Short grain	71.5	565[a]	341[a]	1096[a]	139.5[b]	15.0[a]	234.2[b]	16.8[a]
Long grain	130.9	1084[b]	505[b]	2193[b]	192.7[c]	25.2[ab]	255.2[b]	21.4[a]
SEM	13.8	95.2	44.2	208	19.7	6.5	20.3	5.1
P value	0.001	0.001	0.001	0.001	0.001	0.05	0.01	0.001
Strip loin cuts								
Grass	56.9	508[a]	272.8[a]	836[a]	40.5[a]	14.3[b]	108.8[a]	32.4[b]
Short grain	40.3	358[a]	231.6[a]	590[a]	94.9[b]	6.8[a]	118.8[a]	10.3[a]
Long grain	103.7	899[b]	463.3[a]	1582[b]	172.9[c]	16.1[b]	167.4[b]	14.9[a]
SEM	13.0	97.3	49.4	189	18.9	2.3	12.4	3.2
P value	0.001	0.001	0.001	0.001	0.001	0.01	0.001	0.001
Blade cuts								
Grass	43.9	421[a]	257.5[a]	852[a]	47.0[a]	17.0[b]	147.1	42.1[b]
Short grain	39.1	344[a]	205.5[a]	708[a]	76.5[b]	9.6[a]	163.3	13.5[a]
Long grain	71.7	691[a]	316.2[b]	1502[b]	111.6[c]	15.6[b]	173.4	15.1[a]
SEM	6.8	57.2	29.8	141	13.1	2.3	14.6	4.0
P value	0.001	0.001	0.002	0.001	0.001	0.01	0.20	0.001

[1]Results shown as the mean of 18 determinations. [2]CLA, conjugated linoleic acid (cis-9, *trans*-11 18:2). Within treatments, values followed by the same letter are not significantly different (l.s.d. at *P* = 0.05).

Table 2. Effect of grass, short-term and long-term grain on individual and total longer-chain polyunsaturated fatty acid concentrations of rump, strip loin and blade cuts[1]

	20:4n-6	22:4n-6	20:5n-3	22:5n-3	22:6n-3	LCn-3FA[2]
		Fatty acid concentration (mg/100 g lean meat)				
Rump cuts						
Grass	104.9[b]	6.8[a]	39.8[b]	57.4[b]	7.7	104.9[b]
Short grain	87.9[a]	8.5[a]	23.3[a]	46.9[a]	7.9	78.2[a]
Long grain	100.6[ab]	12.9[b]	20.9[a]	47.6[a]	6.8	75.3[a]
SEM	7.4	0.83	3.2	4.4	0.97	7.8
P value	0.05	0.001	0.001	0.05	0.464	0.001
Striploin cuts						
Grass	59.6[b]	4.4[a]	24.5[b]	36.5[c]	4.2	65.2[c]
Short grain	37.6[a]	4.3[a]	11.1[a]	23.6[a]	3.7	38.3[a]
Long grain	58.5[b]	8.3[b]	13.1[a]	31.6[b]	3.7	48.4[b]
SEM	4.3	0.50	1.9	2.6	0.44	4.7
P value	0.001	0.001	0.001	0.001	0.384	0.001
Blade cuts						
Grass	78.6[c]	6.3[a]	32.0[b]	53.9[b]	7.1[c]	93.0[b]
Short grain	54.8[a]	6.7[a]	14.7[a]	36.9[a]	5.3[b]	56.9[a]
Long grain	65.8[b]	10.2[b]	12.3[a]	36.2[a]	4.2[a]	52.8[a]
SEM	3.9	0.78	2.3	3.2	0.48	5.4
P value	0.001	0.001	0.001	0.001	0.01	0.001

[1]Results shown as the mean of 18 determinations. [2] LCn-3FA, long chain n-3 fatty acid (include 20:5n-3, 22:5n-3 and 22:6n-3). Within treatments, values followed by the same letter are not significantly different (l.s.d. at *P* = 0.05).

treatments. There was a 2- and 3-fold increase in 18:1-*trans* FA content (combination of *trans*-9, -10 and *trans*-11) in rump and strip loin beef cuts of STGF and LTFL compared with beef from cattle fed grass, with a less pronounced but still significant difference in blade.
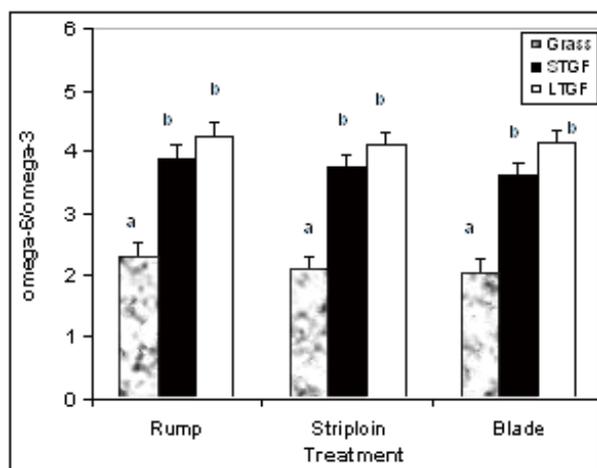
The arachidonic acid (20:4n-6) level in all beef cuts was significantly lower in the STGF compared with grass or LTFL treatments but the 22:4n-6 content was higher in the LTFL group than those cattle fed grass and STGF (Table 2). Regardless of cuts, grass feeding significantly increased the levels of 20:5n-3 and 22:5n-3 relative to STGF and LTFL treatments, but 22:6n-3 was only higher

in blade cuts of grass fed animals. Beef cuts from STGF and LTFL treatments had significantly lower levels of total long chain n-3 FA (20:5n-3, 22:5n-3 & 22:6n-3; Table 2) and total n-3 FA (Table 3) than those cuts from grass fed cattle. The level of total n-6 FA was highest in the LTFL cattle and lowest with grass feeding for all cuts (Table 3).
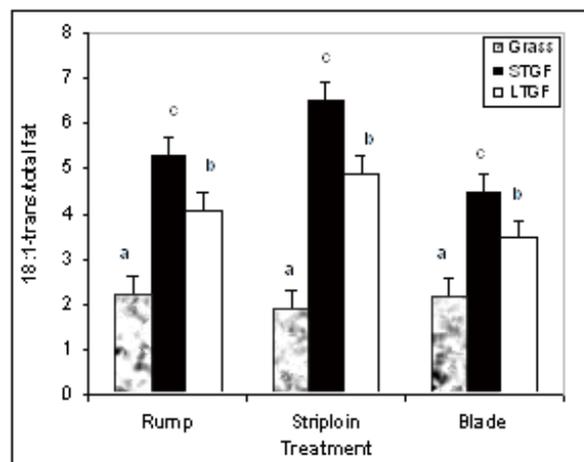
The ratio of n-6/n-3 FA in all cuts was significantly lower for grass feeding compared with other two grain feeding treatments (Fig. 1), while there were no differences observed between cuts. Concentrations of saturated, monounsaturated and total FA were similar with grass and STGF treatments, but these values were significantly higher in the LTFL fed cattle (Table 3). The ratio of 18:1 *trans*/total fatty acids was significantly higher for all cuts from LTFL and STGF fed cattle than those cuts from the grass fed cattle (Fig. 2). The amount of CLA in each cut was similar in the grass fed and LTFL groups, with a lower concentration evident in the STGF group (Table 1), however when viewed as a ratio to total fatty acid content, the grass fed cattle had a higher proportion of CLA ($P < 0.01$) than the LTFL or STGF fed cattle (Fig. 3).

Discussion
Red meat provides significant levels of essential polyunsaturated fatty acids (PUFA), protein, vitamins and minerals in human diets. However, the type of feeding regimens used in beef cattle production can influence the level of essential fats in red meat, due to variations in the fatty acid composition of diet. Red meat from cattle and sheep fed grain is often perceived as not healthy due to presence of relatively high levels of fat in meat cuts,[18] particularly saturated fatty acids, a perception that may impact on consumer choice. If the saturated FA can be reduced and replaced with FA of known health benefits, then it could be expected that consumers would look more favorably on animal products.
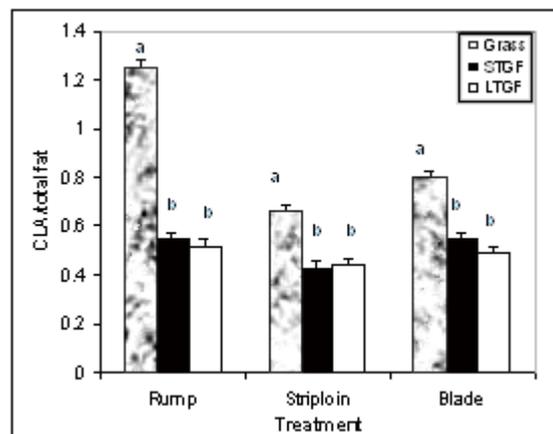

Figure 2. Percent of 18:1-*trans* to total fat in beef cuts from cattle fed grass or short-term and long-term grain feeding. There was no significant effect of cuts or diet x meat cut interaction ($P > 0.05$) observed. There was a significant dietary treatment effect ($P < 0.001$) observed, where the ratios were lowest, moderate and highest for grass, long-term grain and short-term grain regimens, respectively. Within meat cuts, values followed by the same letter are not significantly different ($P > 0.05$).

In spite of such perceptions, we have shown that fat-trimmed beef fed as part of a diet low in saturated fat is associated with significant reductions in serum cholesterol in humans.[19] In recent years, there have been studies devoted to enhancing the essential n-3 PUFA content in beef and lamb,[7-9,18,20,21] and CLA in milk products.[10] In the present study, the main finding was a diet-induced change in functional FA such as n-3 FA, CLA, *trans* fatty acids and ratio of n-6/n-3 FA. The results showed that the essential lipid components of beef could be altered by the feeding system.

Figure 1. Ratio of omega-6 to omega-3 fatty acid content of beef cuts from cattle fed grass or short-term and long-term grain as feedlot rations. There was no significant effect of cuts or diet x meat cut interaction ($P > 0.05$) observed. There was a dietary treatment effect ($P < 0.001$), where beef from grass fed cattle had a markedly lower omega-6/omega-3 ratio than the other two grain fed groups in all three cuts. Within meat cuts, values followed by the same letter are not significantly different ($P > 0.05$).

Figure 3. Percent of conjugated linoleic acid to total fat in beef cuts from cattle fed grass or short-term and long-term grain feeding. There was no effect of cuts or diet x meat cut interaction ($P > 0.05$) observed. A significant dietary treatment effect ($P < 0.001$) was observed, where percent CLA to total fat in beef from grass feeding was markedly higher than short-term or long-term grain feeding. Within meat cuts, values followed by the same letter are not significantly different ($P > 0.05$).

Table 3. Effect of grass, short-term and long-term grain feeding on total saturated (TSFA), total monounsaturated (TMUFA), total omega-3 (Tn-3) and total omega-6 (Tn-6) fatty acid concentrations and EPA (20:5) plus DHA (22:6) of rump, strip loin and blade cuts[1]

	TSFA[2]	TMUFA[2]	TFA[2]	Tn-3FA[2]	Tn-6FA[2]	EPA+DHA[3]
	Fatty acid concentration (mg/100 g lean meat)					
			Rump cuts			
Grass	1118[a]	1185[a]	2792[a]	154.7[b]	334.2[a]	47.5[b]
Shortgrain	1068[a]	1218[a]	2736[a]	96.8[a]	353.7[ab]	31.2[a]
Longgrain	1865[b]	2463[b]	4824[b]	96.6[a]	399.4[b]	27.7[a]
s.e.m.	162.7	237.4	411	11.9	25.6	3.63
P value	0.001	0.001	0.001	0.001	0.04	0.001
			Striploin cuts			
Grass	900[a]	930[a]	2120[a]	97.6[b]	191.6[a]	28.9[b]
Shortgrain	677[a]	639[a]	1538[a]	48.6[a]	173.4[a]	14.9[a]
Longgrain	1568[b]	1729[b]	3614[b]	63.3[ab]	253.8[b]	16.8[a]
s.e.m.	167.8	208.6	383	7.5	15.7	2.12
P value	0.001	0.001	0.001	0.001	0.001	0.001
			Blade cuts			
Grass	801[a]	943[a]	2138[a]	135.1[b]	258	39.1[b]
Shortgrain	644[a]	781[a]	1738[a]	70.4[a]	242	20.0[a]
Longgrain	1172[b]	1663[b]	3175[b]	67.8[a]	272	16.5[a]
s.e.m.	98.6	155.8	265	8.9	17.8	2.5
P value	0.001	0.01	0.001	0.001	0.255	0.001

[1]Results shown as the mean of 18 determinations. [2]TSFA include 14:0, 16:0, saturated branch FA, 18:0, 20:0 and 22:0; TMUFA include 14:1, 16:1, 18:1tr-11, 18:1cis-9 and 20:1; Tn-3 include 18:3, 20:5, 22:5 and 22:6; Tn-6 include 18:2, 20:4 and 22:4. [3]EPA, eicosapentaenoic acid; DHA, docosapentaenoic acid. Within treatments, values followed by the same letter are not significantly different (l.s.d. at *P* = 0.05).

Dietary fat sources

Lipids from grasses and legumes, which form the major part of dietary fats in ruminants, are predominantly glycolipids.[22] The fatty acid content of grass (eg. perennial ryegrass) is very low on a dry matter basis (2–2.5%) and mainly present as esterified fatty acids.[23] Depending on the species of grass, the FA composition varies with 55-70% as linolenic acid (18:3n-3) and 10-20% as linoleic acid (18:2n-6).[23,24] Concentrates used as cattle feed contain less than 5% lipids, except oilseeds, which contain 20–50% lipids on a dry matter basis. The lipids present in cattle feed concentrates are mainly storage triglycerides (90%), but in oil cakes or meals, phospholipids can be up to 40%.[16] Cereal grains (barley, maize, sorghum) and cottonseed used in feedlots involved in this study are rich in 18:2n-6 and contain little 18:3n-3. On the basis of ingredients used in this study, it can be stated that cattle fed grass would have received a high proportion of the PUFA as 18:3n-3 while the STGF and LTFL groups would have a high proportion of 18:2n-6 in their diets.

Functional lipid components (n-3 FA and conjugated linoleic acids) in beef

Lean beef from grass-fed cattle had significantly higher levels of long chain n-3 FA (Table 2) and total n-3 FA (Table 3) than the other two groups fed on grain regimens, due to a significant increase in muscle 18:3 n-3, 20:5n-3 and 22:5n-3 FA with grass feeding. Total long chain n-3 PUFA levels in beef from grass fed cattle were similar to the values found in white fish.[25] We have previously shown that these long chain n-3 PUFA are bioavailable in humans studies.[26] As noted in other studies,[7-9,21] some of the dietary ALA escapes hydrogenation in the rumen and is subsequently metabolized to eicosapentanoic acid (EPA), docosapentaenoic acid (DPA) and

docosahexaenoic acid (DHA), which are found in ruminant tissues (cell membranes). These PUFA were found in all three lean meat cuts of the grass-fed cattle. In contrast, cattle from the STGF and LTFL groups had increased levels of 18:2n-6 in muscles compared with cuts from animals in the grass-fed group (*P* <0.01).

It is interesting to note that though the LTFL group had higher levels of muscle 18:2n-6 in all three cuts (*P*<0.05), there was no increase in arachidonic acid (20:4n-6) levels in muscles. The STGF group had reduced (*P*<0.05) arachidonic acid levels in all cuts compared with cattle fed grass or the LTFL (Table 2) regimens. Short-term grain feeding reduced long chain n-3 FA in muscles without changing muscle total n-6 FA content, but the LTFL regimens reduced (*P*<0.001) long chain n-3 FA while increasing (*P*<0.01) muscle n-6 FA levels. It is clear that with duration of feeding, animals on the LTFL regimens deposited more n-6 FA mainly 18:2n-6 in muscles while reducing the n-3 FA content. Rumen bacteria (*Butyrivibrio fibrisolvens*) have the ability to produce CLA as an intermediate substrate through biohydrogenation of linoleic acid (18:2n-6).[27] It is possible that the main route for CLA (*cis*-9, *trans*-11-C18:2) production in ruminants originates through the delta-9 desaturation of vaccenic acid which originates from rumen metabolism of 18:2n-6.[12]

The concentration of CLA in all meat cuts was lowered by short-term grain feeding (*P*<0.05), but with long-term grain feeding the CLA levels (mg/100 g meat) in all cuts were elevated to levels similar to that found in grass-fed cattle.

Trans fatty acids

The predominant *trans* fatty acid found in grass-fed ruminant animal tissues and milk are CLA and its inter-

mediate metabolite vaccenic (*trans*-11 18:1) acid.[28-30] It has been found that *trans*-10 18:1 is the major *trans* FA in grain fed beef in US compared with European beef where the major *trans* isomer is *trans*-11 18:1.[29] The levels of 18:1-*trans* increased from grass feeding, through STGF to LTFL in the present study.

Human dietary studies have shown that higher levels of dietary *trans* fatty acids, mainly *trans*-9 and -10 18:1 isomers, elevate serum LDL-cholesterol while decreasing serum HDL-cholesterol levels.[31] *Trans* fatty acids also increase serum lipoprotein (a) and triglyceride levels and these are considered risk factors for heart disease.[31] However, others have reported that CLA has a potent effect of reducing diseases such as heart disease and cancer in animals.[10,32] In mammals (human and animals), CLA can be produced endogenously from vaccenic acid (*trans*-11 18:1), whereas the *trans*-10 and *trans*-9 18:1 isomers cannot be bioconverted to CLA.[33] In the present study, meat from the STGF and LTGF cattle did not have an increased CLA content (Fig. 3) although these animals deposited more 18:1-*trans* FA (Fig. 2) in all three cuts. The chromatography technique used in this study did not separate the 18:1-*trans* 11 (vaccenic acid) and 18:1-*trans* 10 isomers, therefore the levels of CLA contributed by vaccenic acid endogenously with the STGF and LTFL diets cannot be explained using the present data.

Major fatty acids and ratio of n-6/n-3 FA content in beef

With maturity, the animals from the LTFL group deposited higher ($P<0.01$) levels of muscle fat than with STGF or grass feeding. This was clear in all three cuts and involved increased levels of saturated (14:0, 16:0 and 18:0), monounsaturated (mainly oleic acid, (*cis* 9-18:1) and n-6 polyunsaturated fatty acids. It is possible that elongase and delta-9 desaturase activity within muscles was higher in the LTFL cattle than other groups as shown by increased levels ($P<0.01$) of stearic and oleic acid in their meat, which was similar to results reported by others.[34,35]

Many human dietary studies have reported that higher intakes of n-3 FA, CLA and 18:1-*trans* 11 have potential to protect cells from diseases such as cancer,[36,37] heart disease[17] and arthritis.[38] Following these observations, animal feeding regimens have been changed to increase the levels of health beneficial fats in ruminant animal products, mainly meat and milk. As evaluated by the ratio of n-6/n-3 and 18:1-*trans* FA/total fat in all three cuts in the present study, the grass-fed regimen markedly reduced ($P<0.001$) the ratio of n-6/n3 in lean beef compared with the other two groups. This was similar to that found in meat from lambs[8,9] and cattle[20] supplemented with n-3 FA rich diets for a short period before slaughter. The significant increase ($P<0.01$) in n-6/n-3 content of meat with short- and long-term grain feeding (Fig. 1) was due to a substantial decrease in muscle 18:3n-3 and long chain n-3 FA content and to an increase in muscle 18:2 n-6 content.

Health implications and marketing aspects

Among the three meat cuts investigated, rump had the highest values of long chain PUFA, CLA, 18:1-*trans* and total FA compared with strip loin or blade cuts. According to recommendations by Food Standards Australia and New Zealand (FSANZ), foods can be labelled as a source of omega- 3 FA if the levels of eicosapentaenoic acid (20:5n-3) plus docosahexaenoic acid (22:6n-3) exceed 30 mg/100g food. Based on this standard, only grass fed animals reached this level. The levels of 20:5n-3 and 22:6n-3 ranged from 15-48mg/100 g lean meat across all cuts. Beef and lamb can contain high levels of docosapentaenoic acid (22:5n-3), which FSANZ do not consider as a long chain n-3 FA from a labelling point of view. The concentration of 22:5n-3 ranged from 24 to 58 mg/100 g lean muscle with the highest ($P <0.01$) values for grass feeding regimens (37-58 mg/100g lean muscle) in all three cuts. Including 22:5n-3, the total long chain n-3 FA ranged from 38 to 105mg/100g of lean meat, with grass feeding having the highest values (69-105mg/100g muscle) in all three meat cuts. Results indicate that grass-fed lean beef can be accredited as 'a source' of n-3 PUFA for those who do not consume fish, because the n-3 FA content is similar to that provided by some white fish.[25,39] There has been little research on the biological value of docosapentaenoic acid (22:5n-3) due to the difficulty of obtaining sufficient pure material to conduct feeding studies. However, there is reason to believe that this FA is an important long chain n-3 PUFA.[40]

Flavor and tenderness are major aspects of meat quality that support beef/lamb marketing, and can be influenced by the animal feeding systems, principally through the effects on the amounts and type of fat in the meat.[21,41] It has been reported that the intensity of flavor increases with increased levels of 18:3n-3 in lamb and beef. Further investigation is needed to examine the effect on flavour and aroma of beef with increased levels of 18:2 n-6, as in LTFL as this may influence the meat flavour.

In conclusion, pasture fed cattle had significantly higher levels of long chain n-3 and total n-3 fatty acids in all three primal meat cuts (rump, striploin, blade) than short-term or long-term grain fed animals. Long-term grain feeding significantly increased muscle total, saturated, monounsaturated, n-6 and 18:1-*trans* fatty acids contents, relative to the other two groups. Beef from short-term grain feeding had similar levels of saturated, monounsaturated, n-6 FA and significantly lower levels of long chain n-3 FA and CLA contents compared with beef from grass feeding. There was an increase in muscle 18:1-*trans* FA in the STGF group and further increased in the LTFL group, suggesting that length of grain feeding is probably a factor for increased *trans* fatty acids in meat due to an increased intake of dietary linoleic acid, the precursor of rumen generated *trans* 18:1 FA. All meat cuts from all three feeding regimens had more than 30mg total long chain n-3 fatty acids per 100g lean meat, with the highest amounts found in rump cuts. Data obtained from this study demonstrate that dietary ingredients of feedlot rations for beef cattle would need to be adjusted to elevate the levels of functional lipids (n-3 PUFA and CLA) in red meat. Hence, from a nutritional point of view, the shift from pasture fed to grain feeding should be discouraged.

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Original Article

Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and *trans* fatty acids in Australian beef cuts: potential impact on human health

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给料系统对澳大利亚牛肉片 omega-3 脂肪酸，共轭亚油酸和顺式脂肪酸含量的影响：对人类健康可能的影响

我们检查了给料系统对澳大利亚牛肉中功能性脂类和其他脂肪酸含量的影响。本研究采用的后腿切割肉，嫩腰切割肉，上脑切割肉是从牧草饲养，短期谷物饲养（80 天，STGF）和长期在饲育场以谷物配料饲养（150-200 天；LTFL）的肉用牛中获取。典型的澳大利亚饲育场配料中大麦和/或高粱的比例超过 50％，STGF 和 LTFL 饲养配料中大麦和/或高粱以纯棉籽或蛋白粉来平衡。分别取从每一种给料方式饲养的 18 头牛的切割肉，剔除可见的脂肪和结缔组织后切碎（300g 瘦牛肉），取 7g 作为平行测定样品分析脂肪酸。牧草饲养的牛肉不管是哪种类型的切割肉其 omega-3 (n-3)脂肪酸)和长链 n-3 脂肪酸的含量显著高于谷物饲养组牛肉（$P<0.0001$）。STGF 切割牛肉与牧草饲养的切割牛肉相比，n-3 脂肪酸和共轭亚油酸 (CLA)水平显著降低，而饱和脂肪酸，单不饱和脂肪酸，n-6 脂肪酸与其相似（$P<0.001$）。LTFL 的切割肉与其他两种给料方式饲养的切割肉相比，相似类型的切割肉饱和脂肪酸，单不饱和脂肪酸，n-6 脂肪酸和顺式 18:1 酸（$P<0.01$）的含量更高，这表明谷物饲养的时间与胴体脂肪沉积相关，延长谷物饲养时间，胴体脂肪沉积越多。从牧草饲养到 STGF，再到 LTGF，顺式 18:1 脂肪酸含量逐渐升高，这表明谷物饲养提高牛肉中顺式脂肪酸含量，这也许是由于摄入 18:2n-6 脂肪酸量增加的缘故。三种给料方式饲养的牛肉中只有牧草饲养的牛肉长链 n-3 脂肪酸含量达到澳大利亚和新西兰食品标准推荐的每 100g 牛肉长链脂肪酸含量超过 30mg 的标准，这个标准是一种食物可以被认为是 omega-3 脂肪酸来源的标准。两种谷物饲养的牛肉顺 18:1 与 n-6 脂肪酸的比例比牧草饲养的牛肉高（$P<0.001$）。本研究得出的实验数据表明谷物饲养降低功能性脂类组分（长链 n-3 脂肪酸和 CLA）的含量，而提高总的顺 18:1 和饱和脂肪酸的含量。

关键词：谷物饲养、肉牛、omega 3 (n-3)脂肪酸、顺式脂肪酸、功能性脂类。