Effect of full-fat hemp seed on performance and tissue fatty acids of feedlot cattle

D. J. Gibb, M. A. Shah, P. S. Mir, and T. A. McAllister[1]

Research Centre, Agriculture and Agri-Food Canada, P. O. Box 3000, Lethbridge, Alberta, Canada T1J 4B1.
LRC contribution no. 38704063. Received 3 November 2004, accepted 17 February 2005.

Gibb, D. J., Shah, M. A., Mir, P. S. and McAllister, T. A. 2005. **Effect of full-fat hemp seed on performance and tissue fatty acids of feedlot cattle**. Can. J. Anim. Sci. **85**: 223–230. Sixty individually penned steers (380 ± 39 kg) were fed barley-based finishing diets containing 0 (control), 9 or 14% full-fat hemp seed (HS) and effects on performance and tissue fatty acid profiles were assessed. At harvest, samples of pars costalis diaphragmatis (PCD) and brisket fat were collected from each carcass. Feeding HS did not affect ($P > 0.25$) dry matter intake (DMI), average daily gain (ADG), or gain feed^{-1}. Carcass traits were also unaffected ($P > 0.35$) by treatment. Feeding HS linearly increased ($P < 0.001$) proportions of C18:0, C18:3 and C18:1 *trans*-9 in PCD, and 18:2 *trans*, *trans* in both PCD and brisket fat. As well, HS linearly increased *cis*-9 *trans*-11 CLA ($P < 0.001$), total saturates ($P = 0.002$) and polyunsaturated fatty acids (PUFA) ($P = 0.01$) in PCD. The presence of C20:4, C20:5 and C22:5 was detected only in tissues of cattle supplemented with HS ($P < 0.06$). Linear reductions ($P < 0.002$) in C16:1 *cis*, C17:1, C18:1 *cis*-9, C20:1, and total unsaturates in PCD, as well as linear decreases in C17:0 ($P = 0.04$) and C17:1 ($P < 0.001$) in brisket fat were observed when HS was fed. Levels of HS up to 14% of dietary DM exerted no detrimental effect on the growth or feed efficiency of cattle as compared to cattle fed a standard barley-based finishing diet. Including HS in the diet had both positive (increased CLA content) and negative (increased *trans* and saturated fats) effects on fatty acid profiles of beef tissues.

Key words: Beef, conjugated linoleic acid, full-fat oilseed, hemp seed, tissue fatty acids

Gibb, D. J., Shah, M. A., Mir, P. S. et McAllister, T. A. 2005. **Incidence des graines de chanvre non délipidées sur le rendement des bovins de boucherie et les acides gras présents dans la viande**. Can. J. Anim. Sci. **85**: 223–230. Soixante bouvillons (380 ± 39 kg) gardés dans des enclos distincts ont reçu une ration de finition à base d'orge contenant 0 (témoin), 9 ou 14 % de graines de chanvre non délipidées (HS). On a étudié l'incidence d'une telle ration sur le rendement et la composition des acides gras dans les tissus. À l'abattage, on a prélevé des échantillons du gras du pars costalis diaphragmatis (PCD) et de la pointe de poitrine de chaque carcasse. L'ingestion de HS ne modifie pas ($P > 0,25$) l'ingestion de matière sèche, le gain quotidien moyen ni le gain selon le type d'aliment. Les paramètres de la carcasse ne sont pas affectés ($P > 0,35$) non plus par le traitement. L'ingestion de HS accroît de façon linéaire ($P < 0,001$) la proportion de C18:0, de C18:3 et de C18:1 *trans*-9 dans le PCD et de 18:2 *trans, trans* dans le PCD et la pointe de poitrine. Le HS augmente aussi linéairement la quantité d'acide linoléique conjugué *cis*-9-*trans*-11 ($P < 0,001$), d'acides gras saturés totaux ($P = 0,002$) et d'acides gras polyinsaturés ($P = 0,01$) dans le PCD. On n'a décelé la présence de C20:4, de C20:5 et de C22:5 que dans les tissus des bovins à qui on avait donné du HS ($P < 0,06$). L'administration de HS entraîne une diminution linéaire ($P < 0,002$) du C16:1 *cis*, du C17:1, du C18:1 *cis*-9, du C20:1 et de l'ensemble des acides gras insaturés dans le PCD ainsi qu'une baisse linéaire du C17:0 ($P = 0,04$) et du C17:1 ($P < 0,001$) dans le gras de la pointe de poitrine. Jusqu'à concurrence de 14 % de la matière sèche des aliments, l'addition de HS n'a aucune incidence néfaste sur la croissance ni sur l'indice de consommation des bovins, comparativement à une ration de finition à base d'orge ordinaire. L'inclusion de HS à la ration a des répercussions positives (hausse de la teneur d'acide linoléique conjugué) et négatives (hausse de la quantité d'acides gras et d'acides gras *trans*) sur le profil des acides gras dans la viande de bœuf.

Mots clés: Bœuf, ALC, oléagineux non délipidés, graines de chanvre, acides gras tissulaires

Feed efficiency and cost of beef production are typically improved as dietary energy is increased in feedlot diets. As a result, high levels of grain are typically included in beef finishing diets. Although fibre sources are usually not a cost-effective source of energy, low levels are routinely included in finishing diets to stimulate rumination and salivation, thereby helping to maintain rumen health and function (Bull et al. 1965; Haskins et al. 1969). Per unit weight, lipids contain more than twice the energy of grains and they are frequently included in diets to increase energy density. However, including isolated fat (i.e., tallow, yellow grease, soapstock) in a feedlot diet requires specialty heating and handling equipment. In addition, governmental restrictions on feeding ruminant protein to ruminants has raised concern about the continued use of fat from ruminants in feedlot diets (Zinn and Plascencia 2004).

Industrial hemp is a potentially valuable crop because of its high yield of fibre that can be used to produce pulp and paper, textiles, or composite boards. It has been legally grown in Canada since 1998 (http://www.hc-sc.gc.ca/english/media/releases/1998/hemp-e.htm). As defined by

[1]*To whom correspondence should be addressed.*

Abbreviations: **ADF**, acid detergent fibre; **ADG**, average daily gain; **CLA**, conjugated linoleic acid; **DMI**, dry matter intake; **HS**, hemp seed; **NDF**, neutral detergent fibre; **PCD**, pars costalis diaphragmatis; **PUFA**, polyunsaturated fatty acids

Health Canada, legally grown hemp contains less than 0.3% delta-9-tetrahydrocannabinol (THC, the psychoactive drug in marijuana). Hemp seed is approximately 30% oil (Leizer et al. 2000) and therefore may be a valuable source of energy in feedlot diets. As well, hemp seed protein has a favourable amino acid profile, resists degradation in the rumen and yet is very digestible in the total gastrointestinal tract (Mustafa et al. 1999).

Within the rumen, most fat is hydrolyzed and unsaturated fatty acids are extensively hydrogenated prior to their absorption and incorporation into meat and milk fats (Harfoot and Hazlewood 1988; Chouinard et al. 2001; Ivan et al. 2001). Despite extensive ruminal modification, diets high in specific unsaturated fatty acids can increase the concentration of those fatty acids in deposited fats (Kelly et al. 1998; Scollan et al. 2001; Gibb et al. 2004). Feeding full-fat oilseeds can reduce the ruminal modification of fatty acids (Baldwin and Allison 1983; Aldrich et al. 1997) and may therefore increase the resemblance between dietary and tissue fatty acids. Hemp seed oil is high in both linoleic (60%) and linolenic (19.3%) acids (Parker et al. 2003), both of which are essential for humans. Through a series of elongation and desaturation reactions, other n-6 and n-3 fatty acids can be formed. Specifically, alpha-linolenic acid can be used as a precursor for the n-3 fatty acids eicosapentanoic (C20:5) and docosahexanoic (C22:6) that may have preventative and therapeutic functions in some inflammatory diseases (Belluzzi 2002). Such effects may explain the improved health and immune response of cattle fed diets high in linolenic acid (Farran et al. 2002a,b). Conjugated linoleic acids (CLA) and/or vaccenic acid (C18:1 *trans*-11) can result from incomplete ruminal hydrogenation of linoleic acid. Desaturation of the 9th carbon of vaccenic acid within adipose tissue will also give rise to *cis*-9 *trans*-11 CLA. Most of the wide-ranging beneficial effects of CLA on animal and human health, reviewed by Mir et al. (2003a) and by Weiss et al. (2004), are attributed to the *cis*-9 *trans*-11 or *trans*-10, *cis*-12 isomers.

No information is available on the feeding value of hemp seed for cattle. Therefore, a feeding experiment was conducted to determine the effect of including HS in feedlot diets on performance (DMI, ADG, and gain feed^{-1}) and fatty acid profiles of meat.

MATERIALS AND METHODS

Upon arrival at the Lethbridge Research Centre in September 2002, 65 yearling steers were weighed, ear tagged, and vaccinated against clostridial diseases (Tasvac 8; Schering Canada Inc., Pointe-Claire, QC), infectious bovine rhinotracheitis, parainfluenza, and *Haemophilus somnus* (Resvac 4/Somnubac; Pfizer Canada, Kirkland, QC), and treated with a pour-on endectocide (Eprinex; Meriel Canada Inc., Victoriaville, QC). Following processing, the steers were moved to individual pens (1.85 m × 6.15 m) and allowed to adjust to their new surroundings prior to initiation of the experiment. After 2 wk, the steers were weighed on 2 consecutive days (day 0 and day 1) for calculation of initial weights as the average of these two measurements. On the basis of the day 0 weights, the 60 most uniform steers were stratified by weight for assignment to three treatment groups (n = 20) so that mean initial weights in the three groups were approximately equal. The experimental diets contained steam-rolled barley grain, barley silage and 0, 9 or 14% HS (Table 1). The 14% level provided 4.0% added fat based on HS containing 28.4% oil. Supplement was included at 5% of DM in all diets and soybean meal was included as needed to maintain iso-nitrogenous diets between treatments. The HS was processed in a roller mill to ensure all seeds were cracked, and was used to replace both barley and silage in each diet so the same grain:silage ratio was maintained as in the control diet. Cattle were adapted from a diet containing 60% silage (DM basis) to a finishing diet (Table 2) containing no more than 9.0% silage using four transition diets fed for 4 or 5 d each. Other than the first one, which contained 0, 4.5, or 7% HS, the transition diets also included HS at 0, 9, or 14% of DM. The supplement contained 17% protein (6 percentage points from urea), minerals and vitamins to meet or exceed National Research Council (1996) recommendations, and 500 mg kg^{-1} monensin sodium to provide 25 mg kg^{-1} in the diet.

Cattle were weighed at 28-d intervals throughout the 166-d trial. Final weights were the average of weights taken on 2 consecutive days. All weights were obtained prior to the morning feed delivery. All cattle were cared for in accordance with guidelines provided by the Canadian Council on Animal Care (CCAC 1993).

Dietary ingredients were analyzed prior to initiation of the trial as well as monthly throughout the trial. Dry matter content was determined by drying in a forced-air oven at 55°C for 48 h. Samples of dried feed were ground to pass through a 1-mm screen and analyzed for neutral detergent fibre (NDF) and acid detergent fibre (ADF) with α-amylase included in the analyses (Van Soest et al. 1991). Protein content was determined using a Carlo Erba® NA 1500 Carbon-Nitrogen elemental analyzer (Carlo Erba Strumentazione, Rodano, Milan, Italy). Mineral levels were determined by inductively coupled plasma optical emission spectrometry. Lipids were extracted using modified procedures of Jiang et al. (1996). Briefly, ground (feed) or chopped (tissue) samples were homogenized in 15 mL of isopropanol. After addition of 10 mL of hexane, the mixture was homogenized and filtered through Whatman No. 1 filter paper. Test tubes and filter paper were rinsed with hexane:isopropanol solution (10:14, vol vol^{-1}). The homogenate was combined with 8 mL of 6.68% (wt vol^{-1}) aqueous sodium sulphate, then centrifuged (640 × g) for 10 min. The hexane layer was collected and evaporated under nitrogen, and the fatty acid content of the oil was determined after direct transmethylation as described by Park and Goins (1994).

Fatty acid methyl esters were analyzed by gas chromatography using a model HP6890 gas chromatograph (Hewlett-Packard, San Fernando, CA) equipped with a flame ionization detector, an HP18596B autosampler and an HP7673A injector (Hewlett Packard Ltd., Mississauga, ON). The column was fused silica capillary (CP Sil 88, DB-23, 60 m × 0.25 mm, 0.25-mm film thickness; Agilent Technologies, Mississauga, ON), and the carrier gas was helium at a flow rate of 1.7 mL min^{-1}. Injector and detector

Table 1. Compositional analysis of ingredients used to prepare experimental diets

	Dietary ingredient		
	Barley silage	Barley grain	Hemp seed
Composition (%, DM basis)			
Dry matter	40.0	91.0	91.3
Protein	10.7	13.5	27.4
NDF	45.9	23.8	33.4
ADF	27.7	6.6	23.3
Calcium	0.21	0.02	0.41
Phosphorus	0.16	0.32	1.12
Magnesium	0.12	0.16	0.56
Potassium	0.56	0.21	0.88
Sodium	0.16	ND[z]	0.02
Sulphur	0.13	0.08	0.32
Ether extract	1.6	2.5	28.4
Individual fatty acids (% of total fatty acids)			
C16:0	29.2	19.8	6.9
C18:0	3.8	1.5	2.7
C18:1	36.7	13.2	10.5
C18:2	18.1	55.3	53.9
C18:3	1.5	5.5	24.6

[z]ND, not detected.

Table 2. Formulas of experimental finishing diets

	Treatment (hemp seed content, as-fed)		
	0%	9%	14%
Ingredients (%, as-fed)			
Barley grain	81.4	74.8	73.3
Barley silage	9.0	8.2	7.7
Hemp seed	0.0	9.0	14.0
Supplement	5.0	5.0	5.0
Soybean mean	4.6	3.0	0.0
Compositional analysis (%, DM basis)[z]			
Dry matter	77.0	77.0	78.2
Protein	15.1	15.6	15.0
NDF	16.8	17.5	18.5
ADF	5.3	5.2	6.0
Ether extract	1.8	3.4	5.9

[z]Determined from diet sample composites (n = 5).

temperatures were set at 225°C and 300°C, respectively, and temperature was programmed as follows: 50 to 175°C, at 25°C min^{-1}; held at 175°C for 20 min; 175 to 225°C at 5°C min^{-1}; held at 225°C for 15 min. Run time was 51 min. Peak area was measured with a HP 3365 integrator, and the concentration of each fatty acid was calculated on the basis of relative peak areas of standard fatty acids (Sigma Chemical Co., St. Louis, MO) at their retention times.

Orts were collected weekly and on weigh days, immediately before steers were weighed. Orts were dried for determining DM content as described above. Dry matter intake was calculated weekly as (feed delivered × $\%DM_{feed}$) – (orts collected × $\%DM_{orts}$). Dry matter intake, ADG, and gain feed^{-1} were calculated for each period that animal weights were obtained.

At harvest, carcass characteristics including warm carcass weight (with kidneys removed), dressing percentage, backfat thickness, and quality grade, were obtained. Samples of pars costalis diaphragmatis muscle (diaphragm) and subcutaneous fat (brisket) were also taken from each animal. Tissue samples were immediately frozen on dry ice; lipids were subsequently removed from tissues using hexane extraction and fatty acid content of the triglyceride fraction was determined as previously described. Liver abscesses were ranked based on severity (Brown et al. 1975) using a numeric scale from 0 (no abscesses) to 3 (severely abscessed; more than four small abscesses or at least one abscess greater than 2.5 cm in diameter).

Statistical Analysis

Individual animal was the experimental unit, with diet as the only class variable. Dry matter intake, ADG, and gain feed^{-1} were compared statistically between treatments using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) using the residual error as the error term. The same statistical model was used to compare fatty acid levels between treatments. Orthogonal contrasts were used to compare HS to no HS in the diet as well as the linear and quadratic effects of including 0, 9, or 14% HS.

RESULTS AND DISCUSSION

The experimental diets were fed for 166 d, during which total gain by the steers averaged 190 kg head^{-1}. They were sold to a commercial abbatoir on 2003 Apr. 01. No differences between treatments were observed (Table 3) for DMI ($P > 0.85$; 8.70 kg d^{-1}), ADG ($P > 0.48$; 1.14 kg), or gain feed^{-1} ($P > 0.13$; 0.131). These values are slightly decreased from those typically observed for pen-fed cattle. For example, DMI averaged only 1.8% of average body weight. A survey of feedlots in southern Alberta that sold finished steers of comparable weight (3778 total animals in 22 different groups) in the first quarter of 2003 revealed DMI averaging 11.2 kg d^{-1}, for an average intake of 2.1% of body weight (Gibb, unpublished data). Individually fed animals consume less than pen-fed cattle (Kidwell et al. 1954; Warnick et al. 1977; Phipps et al. 1983), which likely contributed to the lower than expected intakes and performance.

Compositional analyses of the dietary ingredients (Table 1) revealed that HS contained 33.4% NDF, 27.4% protein and 28.4% oil (DM basis; n = 5). Sixteen C and 18 C fatty acids accounted for 98.6% (by weight) of the fatty acids in the oil (C16:0, 6.9%; C18:0, 2.7%; C18:1 *cis*-9, 10.5%; C18:2 *cis, cis*, 53.9%; and C18:3, 24.6%). The gamma isomer accounted for 3.5 of the 24.6 percentage points of linolenic acid.

Analysis of diet samples collected over the course of the experiment revealed that fat content increased from 1.83% in the control diet to 3.42 and 5.90% with the addition of 9 and 14% HS, respectively (Table 2). The addition of fat or oils has reduced DMI with corn-based diets (Krehbiel et al. 1995; Zinn and Shen 1996; Ramirez and Zinn 2000), but supplementary lipid appears to have neutral or even positive effects (Brethour et al. 1986; Brandt et al. 1988; Bock et al. 1991) in diets with grains that contain less oil (barley and wheat) and are more rapidly fermented than corn. Other research at our facility showed that DMI by feedlot cattle was not consistently increased when full-fat sunflower seed was added to barley-based diets, as a source of sunflower oil, to levels up to 8% total fat (Gibb et al. 2004). Inconsistent DMI response to lipid supplementation reflects the complexity of both intake regulation and ruminal fatty acid metabolism.

Table 3. Performance of steers fed barley-based finishing diets containing 0, 9 or 14% full-fat hemp seed (as-fed)

Item	Treatment (dietary hemp seed)					
	0%	9%	14%	SEM	*P* value[z]	0 vs. 9 & 14[y]
Initial weight (kg)	378.1	380.5	380.4	8.9	0.98	0.19
Days 0 to 56						
DMI (kg d^{-1})	10.31	10.34	10.36	0.36	0.99	0.90
Average daily gain (kg)	1.23	1.14	1.27	0.08	0.54	0.82
Gain $feed^{-1}$	0.118	0.108	0.121	0.006	0.24	0.62
Days 57 to 166						
DMI (kg d^{-1})	7.80	7.87	7.89	0.28	0.98	0.83
Average daily gain (kg)	1.13	1.09	1.10	0.05	0.88	0.65
Gain $feed^{-1}$	0.144	0.138	0.140	0.004	0.56	0.32
Days 1 to 166						
DMI (kg d^{-1})	8.65	8.71	8.72	0.30	0.98	0.86
Average daily gain (kg)	1.16	1.11	1.16	0.05	0.74	0.66
Gain $feed^{-1}$	0.133	0.126	0.133	0.004	0.27	0.32
Final weight (kg)	571.4	564.8	573.0	15.7	0.93	0.62

[z]Significance of differences between treatments.
[y]Significance of effect of hemp seed in diet compared with feeding no hemp seed.

Hemp seed did not ($P > 0.32$) affect rate or efficiency of gain (Table 3). Increased efficiencies are expected when dietary energy concentration is increased if DMI is not reduced. Fat or oil supplementation has improved the efficiency of feed utilization by feedlot cattle fed barley-based finishing diets in most (Zinn 1988, 1989) but not all (Engstrom et al. 1994) experiments. Similarly, with corn-based diets, fat or oil supplementation has improved feed efficiency in some (Brandt et al. 1992; Zinn 1992; Krehbiel et al. 1995) but not all (Johnson and McClure 1973; Buchanan-Smith et al. 1974; Huffman et al. 1992) feeding trials. Supplemental lipids should be of greater benefit with diets based on barley or wheat than with diets based on corn, because of the lower fat content of barley and wheat (Brandt 1988; Zinn and Plascencia 2002). However, efficiency is not always improved by adding fat or oil even with wheat-based diets (Zinn 1992). Providing supplemental oil through sunflower seed improved rate and efficiency of gain in only one of the two experiments conducted by Gibb et al. (2004). Inconsistencies in the response to added lipid are particularly perplexing when DMI is not affected. Although fats have more than twice the energy content of the carbohydrates they typically displace, digestibility and utilization may be moderately influenced by chain length and degree of saturation (Andrews and Lewis 1970). As well, long-chain polyunsaturated fatty acids (PUFA) are potentially toxic to ruminal microbes, particularly protozoa and cellulolytic bacteria (Palmquist and Jenkins 1980), contributing to a reduction in microbial activity and subsequent digestion.

Feeding HS had no effect on final liveweight ($P = 0.62$; 566 kg), carcass weight ($P = 0.94$; 326 kg), or dressing percentage ($P = 0.36$; 57.3%). Other carcass traits (Table 4) including backfat, ribeye area, quality grade and meat yield were also unaffected by including HS in the diet. Feeding supplemental lipids often enhances carcass fat (Andrae et al. 2001; Felton and Kerley 2004). The incidence of liver abscesses was quite high in this experiment, but dietary HS did not affect the occurrence of total ($P = 0.61$) or severely ($P = 0.63$) abscessed livers, which averaged 60 and 51%, respectively. Performance is typically not affected by moderately abscessed livers, but it can be when liver abscesses are severe (Brown et al. 1975; Brink et al. 1990). In the current experiment, however, Pierson correlation coefficients (SAS Institute Inc., Cary, NC) indicated that ADG ($P = 0.16$), gain $feed^{-1}$ ($P = 0.16$), and DMI were not ($P = 0.29$) affected by the presence of severely abscessed livers. Nineteen percent of the cattle had abscessed lungs at slaughter, which also did not affect DMI ($P = 0.94$), ADG ($P = 0.98$) or gain $feed^{-1}$ ($P = 0.72$). Although the abscessed lungs and severely abscessed livers did not influence performance in this experiment, it is feasible that they are a reflection of sub-clinical health challenges that may have contributed to the poor performance.

Fatty Acids

Despite extensive hydrogenation of fatty acids in the rumen (Harfoot and Hazelwood 1988), alterations in fatty acid profiles of brisket fat (Table 5) and PCD (Table 6) were detected when HS was fed. Consistent with earlier reports (Dryden and Marchello 1973; Garrett et al. 1976; Hogan and Hogan 1976), responses among tissues were not consistent and are likely the result of differences in accretion of specific fatty acids (Hood and Thornton 1976) and/or differences in desaturase activity (Chang et al. 1992) between tissues.

Proportions of 16:1 *cis* were reduced in PCD with HS supplementation. Beaulieu et al. (2002) similarly reported that including 5% soybean oil in corn-based finishing diets reduced proportions of 16:1 in the loin and hind quarter. Feeding full-fat canola seeds has also reduced levels of C16:0 and C16:1 in beef tissues (St. John et al. 1987; Rule et al. 1994). Sixteen C fatty acids are commonly reduced in deposited fat when oils are supplemented in the diet (Markus et al. 1996; Mir et al. 2003b; Gibb et al. 2004), a response that likely reflects reduced de novo fatty acid synthesis in tissues (Kim et al. 2003; Vernon 1976) and/or dilution resulting from increased levels of 18 C fatty acids.

Levels of 17:1 in PCD were reduced (by 19.5%; $P < 0.001$) by feeding HS, as were both C17:0 (by 21%; $P < 0.01$) and C17:1 (by 20.1%; $P < 0.001$) in brisket fat. Rumen

Table 4. Carcass traits of steers fed barley-based finishing diets containing 0, 9 or 14% full-fat hemp seed (as-fed)

	Treatment (dietary hemp seed)					
Item	0%	9%	14%	SEM	*P* value[z]	0 vs. 9 & 14[y]
Carcass weight (kg)	325.7	323.0	330.2	9.6	0.87	0.94
Dressing percentage	56.8	57.3	57.7	0.49	0.47	0.27
Backfat (mm)	14.7	14.1	16.3	0.97	0.26	0.66
Ribeye area (cm^2)	79.5	78.9	96.3	12.6	0.54	0.60
Quality grade[x]	2.47	2.26	2.42	0.13	0.49	0.41
Meat yield (%)	54.9	55.2	57.0	2.84	0.85	0.72
Abscessed livers (%)	52.6	68.4	57.9	11.5	0.61	0.46
Severely abscessed livers (%)	42.1	57.9	52.6	11.7	0.63	0.36
Abscessed lungs (%)	15.8	21.1	21.1	9.3	0.90	0.65

[z]Significance of differences between treatments.
[y]Significance of effect of hemp seed in diet compared with feeding no hemp seed.
[x]Calculated on the basis of the Canadian grading system, in which 1 = A, 2 = AA and 3 = AAA. In this study, 3.5, 54.4 and 42.1% of the steers graded A, AA and AAA, respectively.

Table 5. Fatty acid composition (g 100 g^{-1} total FA) of brisket fat samples from steers fed barley-based finishing diets containing 0, 9 or 14% full-fat hemp seed

	Treatment (dietary hemp seed)						
	0%	9%	14%	SEM	*P* value[z]	*P* value (linear)[y]	0 vs. 9 & 14[x]
C14:0	3.43	3.31	3.49	0.25	0.87	0.81	0.94
C14:1 *cis*	1.89	2.23	1.92	0.22	0.50	0.94	0.49
C16:0	26.72	25.00	24.08	1.12	0.32	0.18	0.15
C16:1 *trans*	0.25	0.21	0.22	0.02	0.32	0.36	0.15
C16:1 *cis*	7.55	8.16	7.55	0.74	0.75	0.77	0.71
C17:0	1.59*a*	1.27*b*	1.24*b*	0.10	0.04	0.04	0.01
C17:1	1.85*a*	1.59*b*	1.36*c*	0.06	<0.001	<0.001	<0.001
C18:0	7.23	7.15	8.00	0.54	0.52	0.30	0.62
C18:1 *trans*-9	1.83	1.74	1.74	0.59	0.99	0.93	0.90
C18:1 *cis*-9	44.07	45.39	41.32	1.57	0.22	0.18	0.72
C18:2 *trans, trans*	0.22*b*	0.45*a*	0.43*a*	0.04	0.002	0.008	0.006
C18:2 *cis, cis*	1.49	1.58	1.40	0.13	0.66	0.56	0.99
C18:3	0.32	0.41	0.41	0.04	0.19	0.18	0.07
C20:0	0.05*b*	0.06*b*	0.08*a*	0.02	0.03	0.01	0.05
C20:1	0.23	0.19	0.17	0.02	0.18	0.09	0.08
C20:4	0.00*b*	0.03*a*	0.02*ab*	0.01	0.02	0.25	0.01
C22:5	0.00	0.02	0.02	0.01	0.15	0.21	0.06
CLA *cis*-9, *trans*-11	0.41	0.48	0.53	0.07	0.50	0.26	0.28
CLA *trans*-10, *cis*-12	0.04	0.06	0.04	0.01	0.28	0.81	0.42
Saturated	39.82	37.47	37.82	1.69	0.58	0.50	0.31
Unsaturated	60.15	65.52	62.16	1.69	0.58	0.50	0.31
Saturated/unsaturated	0.67	0.60	0.63	0.04	0.54	0.31	0.60

[z]Significance of differences between treatments.
[y]Significance of linear effect of hemp level in diets.
[x]Significance of effect of hemp seed in diet compared with feeding no hemp seed.
a-c Within a row, values followed by different letters differ ($P < 0.05$).

microbes are the primary source of odd carbon fatty acids in beef tissues (Keeney and Katz 1962). Although synthesis of odd chain fatty acids did not change with fat supplementation in trials conducted by Wu et al. (1991), those researchers described and cited other studies that demonstrated how fat supplementation spares de novo synthesis of fatty acids by rumen microorganisms. As with 16 C fatty acids, increased levels of 18 C fatty acids may have reduced 17 C fatty acids through simple dilution. However, reduced levels of 17 C may also result from a decline in ruminal production of odd chain precursors such as propionate. Proportions of 17:0 were also reduced in brisket fat when sunflower seed was fed (Gibb et al. 2004). As well, levels of 17:0 and 17:1 have been reduced in milk when sunflower seed or oil was fed to dairy cows (Shah et al. 2004). Soybean oil (5%) has increased levels of C17:0 in the forequarter, but had no effect on fat from loin or hindquarter (Beaulieu et al. 2002). Levels of 17 C fatty acids are often not reported in the literature so it is not clear if the effects of fat supplementation on tissue levels have been consistent.

Levels of C20:1 were decreased in PCD (by 22.2%; $P = 0.002$) with HS supplementation, with a trend toward reduction (by 20.4%; $P = 0.08$) in brisket fat. Dilution arising from increased levels of other fatty acids may have contributed to these reduced C20:1 levels, but the opposite response (also consistent across tissues) was observed when canola seed was fed to cattle (Rule et al. 1994). Whether differences in oil source and level between experiments resulted in differences in fatty acid availability or in metabolism in the tissue (e.g., elongase, desaturase activity) is not clear.

Table 6. Fatty acid composition (g 100 g^{-1} total FA) of pars costalis diaphragmatic (PCD) samples from steers fed barley-based finishing diets containing 0, 9 or 14% full-fat hemp seed

	Treatment (dietary hemp seed)			SEM	*P* value[z]	*P* value (linear)[y]	0 vs. 9 & 14[x]
	0%	9%	14%				
C14:0	3.05	3.11	3.29	0.14	0.44	0.21	0.36
C14:1 *cis*	0.58	0.56	0.51	0.04	0.49	0.24	0.42
C16:0	25.59	25.11	25.08	0.44	0.65	0.45	0.35
C16:1 *trans*	0.30	0.30	0.29	0.01	0.88	0.65	0.83
C16:1 *cis*	3.28*a*	2.88*b*	2.75*b*	0.08	<0.001	<0.001	<0.001
C17:0	1.82	1.69	1.75	0.05	0.16	0.46	0.09
C17:1	1.13*a*	0.92*b*	0.89*b*	0.04	<0.001	<0.001	<0.001
C18:0	14.62*b*	16.90*a*	18.27*a*	0.51	<0.001	<0.001	<0.001
C18:1 *trans*-9	2.23*b*	3.32*a*	4.19*a*	0.35	<0.001	<0.001	0.008
C18:1 *cis*-9	42.83*a*	39.64*b*	37.78*b*	0.90	<0.001	<0.001	<0.001
C18:2 *trans, trans*	0.15*c*	0.31*b*	0.37*a*	0.01	<0.001	<0.001	<0.001
C18:2 *cis, cis*	2.69	3.08	2.67	0.17	0.11	0.99	0.19
C18:3	0.39*b*	0.60*a*	0.59*a*	0.03	<0.001	<0.001	<0.001
C20:0	0.13	0.12	0.13	0.02	0.94	0.82	0.99
C20:1	0.21*a*	0.17*b*	0.16*b*	0.01	<0.01	0.009	0.002
C20:4	0.26	0.35	0.29	0.04	0.35	0.85	0.29
C22:5	0.08	0.11	0.09	0.01	0.16	0.75	0.15
CLA *cis*-9, *trans*-11	0.21*b*	0.27*ab*	0.28*a*	0.01	<0.001	<0.001	<0.001
CLA *trans*-10, *cis*-12	0.00	0.00	0.01	0.00	0.49	0.25	0.46
Saturated	45.76*b*	47.47*ab*	49.11*a*	0.71	<0.01	0.002	0.005
Unsaturated	54.24*a*	52.52*ab*	50.88*b*	0.71	<0.01	0.002	0.005
Saturated/Unsaturated	0.85*b*	0.91*ab*	0.97*a*	0.03	0.008	0.002	0.007

[z]Significance of differences between treatments.
[y]Significance of linear effect of hemp level in diets.
[x]Significance of effect of hemp seed in diet compared with feeding no hemp seed.
a–c Within a row, values followed by different letters differ ($P < 0.05$).

Feeding HS resulted in notable increases in 18 C fatty acids, including increased ($P < 0.001$) proportions of C18:0 (+20.3%) and C18:1 *trans*-9 (+68.3%) in PCD and C18:2 *trans trans* ($P < 0.001$) in both PCD (+128%) and brisket fat (+100.5%). Increased levels of C18:0 likely result from complete hydrogenation of the 18 C fatty acids provided by HS or from reduced desaturation activity in the tissues. Other 18 C *trans* fatty acids (i.e., vaccenic acid; C18:1 *trans*-11) may also have increased, but their peaks could not be isolated with the 60-m column used. Increased levels of *trans* fatty acids are a result of ruminal modification of the unsaturated fats provided from HS. Duodenal flows of C18:1 *trans* have been increased fourfold with supplementation of high linoleic acid sunflower oil (Kalscheur et al. 1997). Biohydrogenation of unsaturated fatty acids includes an intermediate step where *trans* fatty acids are produced in the rumen (Smith et al. 1978; Jenkins 1993). Although linoleic acid levels were not affected by feeding HS, its derivative, arachidonic acid (C20:4), was detected in brisket fat only with when the diet included HS.

Dietary PUFA reduce Δ-9 desaturase activity in mice (Ntambi 1999) and may explain reduced levels of C18:1 *cis*-9 in PCD tissue. Beaulieu et al. (2002) found numeric reductions in C18:1 *cis*-9 and desaturase activity in most tissues when 5% soybean oil was fed in a finishing diet. The notable exception was in fat extracted from the small intestine.

Levels of n-3 fatty acids in tissues were also increased with HS supplementation. Specifically, C18:3 was increased in PCD (+51.4%; $P = 0.001$) and moderately increased in brisket fat (+29.8%; $P = 0.07$). Levels of 18:3 have been increased with the supplementation of a corn-based finishing diet with soybean oil (Beaulieu et al. 2002) and levels were increased in both diaphragm and brisket tissues with sunflower seed supplementation in the study conducted by Gibb et al. (2004). Including full-fat flax seed in barley-based (Maddock et al. 2003) and corn-based (LaBrune et al. 2002) feedlot diets has also increased linolenic acid content of tissues. Other n-3 fatty acids such as eicosapentanoic (C20:5) in PCD ($P = 0.04$) and docosapentanoic (C22:5) in brisket ($P = 0.06$) were present only when HS was fed.

Proportions of PUFA were increased ($P = 0.007$; data not shown) in PCD as a result of feeding HS, but total unsaturates were decreased ($P = 0.005$), resulting in an increase ($P = 0.005$) in the saturate:unsaturate ratio.

Although the proportion of *trans*-10 *cis*-12 CLA isomer in total CLA often increases with increasing grain content of the diet (Bauman et al. 2000; Piperova et al. 2000; Beaulieu et al. 2002), only *cis*-9 *trans*-11 was increased (+32.1%; $P < 0.001$) with HS supplementation, and this was seen only in PCD tissue. The *cis*-9 *trans*-11 isomer is thought to provide greater anti-cancer benefits for humans (MacDonald 2000). Increased CLA deposition with oil supplementation has been observed in some (Ivan et al. 2001; Mir et al. 2003b; Gibb et al. 2004;) but not all trials (McGuire et al. 1998; Beaulieu et al. 2002)

This research documents that HS can favourably alter carcass fat by increasing levels of CLA and n-3 fatty acids without negatively affecting performance. In the event that a viable hemp fibre industry is established in Canada, full-fat hemp that does not meet seed grade could prove to be a valuable source of energy and protein in feedlot diets.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Alberta Safflower Growers' Association for partially funding this research and the Lethbridge Research Centre feedlot staff for their care of the steers.

Aldrich, C. G., Merchen, N. R., Drackley, J. K., Gonzales, S. S., Fahey, G. C., Jr. and Berger, L. L. 1997. The effects of chemical treatment on whole canola seed on lipid and protein digestion by steers. J. Anim. Sci. **75**: 502–511.

Andrae, J. G., Ducket, S. K., Hunt, C. W., Pritchard, G. T. and Owens, F. N. 2001. Effects of feeding high-oil corn to beef steers on carcass characteristics and meat quality. J. Anim. Sci. **79**: 582–588.

Andrews, R. J. and Lewis, D. 1970. The utilization of dietary fats by ruminants. II. The effect of fatty acid chain length and unsaturation on digestibility. J. Agric. Sci. **75**: 55–60.

Baldwin, R. L. and Allison, M. J. 1983. Rumen metabolism. J. Anim. Sci. **57**(Suppl. 2): 461–477.

Bauman, D. E., Baumgard, L. H., Corl, B. A. and Griinari, J. M. 2000. Biosynthesis of conjugated linoleic acid in ruminants. Proc. Am. Soc. Anim. Sci. 1999. Online [Available]: http://www.asas.org/jas/symposia/proceedings/0937.pdf.

Beaulieu, A. D., Drackley, J. K. and Merchen, N. R. 2002. Concentrations of conjugated linoleic acid (*cis*-9, *trans*-11-octadecadienoic acid) are not increased in tissue lipids of cattle fed a high-concentrate diet supplemented with soybean oil. J. Anim. Sci. **80**: 847–861.

Belluzzi, A. 2002. N-3 fatty acids for the treatment of inflammatory bowel diseases. Proc. Nutr. Soc. **61**: 391–395.

Bock, B. J., Harmon, D. L., Brandt, R. T., Jr. and Schneider, J. E. 1991. Fat source and calcium level effects on finishing steer performance, digestion, and metabolism. J. Anim. Sci. **69**: 2211–2224.

Brandt, R. T., Jr., Anderson, S. J. and Elliot, J. K. 1988. Effect of supplemental fat on performance and carcass traits of finishing cattle fed milo or wheat processed by two methods. Page 555 *in* Kansas Agric. Exp. Sta. Rep. Prog.

Brandt, R. T., Jr., Kuhl, G. L., Campbell, R. E., Kastner, C. L. and Stroda, S. L. 1992. Effects of steam-flaked sorghum grain or corn and supplemental fat on feedlot performance, carcass traits, longissimus composition, and sensory properties of steers. J. Anim. Sci. **70**: 343–348.

Brethour, J. R., Riley, J. G. and Lee, R. W. 1986. Adding fat and/or sodium bicarbonate to steer finishing rations that contain wheat. Page 494 *in* Kansas Agric. Exp. Sta. Rep. Prog.

Brink, D. R., Lowry, S. R., Stock, R. A. and Parrot, C. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. J. Anim. Sci. **68**: 1201–1207.

Brown, H., Bing, R. F., Grueter, H. P., McAskill, J., Cooley, C. O. and Rathmacher, R. P. 1975. Tylosin and chlortetracycline for the prevention of liver abscesses, improved weight gains, and feed efficiency in feedlot cattle. J. Anim. Sci. **40**: 207–213.

Buchanan-Smith, J. G., Macleod, G. K. and Mowat, D. N. 1974. Animal fat in low-roughage diets for ruminants: The effects of nitrogen source and an amino acid supplement. J. Anim. Sci. **38**: 133–139.

Bull, L. S., Bush, L. J., Friend, J. D., Harris, B. and Jones, E. W. 1965. Incidence of ruminal parakeratosis in calves fed different rations and its relation to volatile fatty acid absorption. J. Dairy Sci. **48**: 1459–1466.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. Vol. 1. 2nd ed. E. D. Olfert, B. M. Cross, and A. A. McWilliam, eds. Canadian Council on Animal Care, Ottawa, ON.

Chang, J. H. P., Lunt, D. K. and Smith S. B. 1992. Fatty acid composition and fatty acid elongase and stearoyl-CoA desaturase activities in tissues of steers fed high oleate sunflower seed. J. Nutr. **122**: 2074–2080.

Chouinard, P. Y., Corneau, L., Butler, W. R., Chilliard, Y., Drackley, J. K. and Bauman, D. E. 2001. Effect of dietary lipid source on conjugated linoleic acid concentrations in milk fat. J. Dairy Sci. **84**: 680–690.

Dryden, F. D. and Marchello, J. A. 1973. Influence of dietary fats upon carcass lipid composition in the bovine. J. Anim. Sci. **37**: 33–39.

Engstrom, D. F., Goonewardene, L. A., Grimson, R. E., McKinnon, J. J., Stilborn, R. P. and Volek, R. 1994. Effects of feeding added protein and fat on feedlot performance and carcass quality in large frame steers. Can. J. Anim. Sci. **74**: 547–549.

Farran, T., Droulliard, J. S., Blasi, D. B., LaBrune, H. J., Montgomery, S. P., Sindt, J. J., Coetzer, C. M., Hunter, R. D. and Higgins, J. J. 2002a. Evaluation of performance in receiving heifers fed different sources of dietary lipid. Kansas Agric. Exp. Sta. Rep. Prog. **890**: 1–5.

Farran, T., Drouillard, J. S., Blasi, D. B., Spire, M. F, Sindt, J. J., Montgomery, S. P., Coetzer, C. M., LaBrune, H. J., Minton, J. E., Higgins, J. J. and Elasser, T. H. 2002b. Immune response in feeder cattle fed different sources of dietary lipid. Kansas Agric. Exp. Sta. Rep. Prog. **890**: 5–9.

Felton, E. E. D. and Kerley, M. S. 2004. Performance and carcass quality of steers fed different sources of dietary fat. J. Anim. Sci. **82**: 1794–1805.

Garrett, W. N., Yang, Y. T., Dunkley, W. L. and Smith, L. M. 1976. Energy utilization, feedlot performance and fatty acid composition of beef steers fed protein encapsulated tallow or vegetable oils. J. Anim. Sci. **42**: 1522–1533.

Gibb, D. J., Owens, F. N., Mir, P. S., Mir, Z., Ivan, M. and McAllister, T. A. 2004. Value of sunflower seed in finishing diets of feedlot cattle. J. Anim. Sci. **82**: 2679–2692.

Harfoot, C. G. and Hazlewood, G. P. 1988. Lipid metabolism in the rumen. Page 285 *in* P. N. Hobson, ed. The rumen microbial ecosystem. Elsevier Appl. Sci., London, UK.

Haskins, B. R., Wise, M. B., Craig, H. B., Blumer, T. N. and Barrick, E. R. 1969. Effects of adding low levels of roughages or roughage substitutes to high energy rations for fattening steers. J. Anim. Sci. **29**: 345–353.

Hogan, J. P. and Hogan, R. M. 1976. The evaluation of formaldehyde-treated sunflower seed-casein supplement as a source of linoleic acid for ruminant lipids [sheep]. Aust. J. Agric. Res. **27**: 129–138.

Hood, R. L. and Thornton, R. F. 1976. Site variation in the deposition of linoleic acid in adipose tissue of cattle given formaldehyde-treated sunflower seed. Aust. J. Agric. Res. **27**: 895–902.

Huffman, R. P., Stock, R. A., Sindt, M. H. and Shain, D. H. 1992. Effect of fat type and forage level on performance of finishing cattle. J. Anim. Sci. **70**: 3889–3898.

Ivan, M., Mir, P. S., Koenig, K. M., Rode, L. M., Neill, L., Entz, T. and Mir, Z. 2001. Effects of dietary sunflower seed oil on rumen protozoa population and tissue concentration of conjugated linoleic acid in sheep. Small Rumin. Res. **41**: 215–227.

Jenkins, T. C. 1993. Lipid metabolism in the rumen. J. Dairy Sci. **76**: 3851–3863.

Jiang, J., Bjoerck, L., Fonden, R. and Emanuelson, M. 1996. Occurrence of conjugated *cis*-9, *trans*-11-octadecadienoic acid in bovine milk: effects of feed and dietary regimen. J. Dairy Sci. **79**: 438–445.

Johnson, R. R. and McClure, K. E. 1973. High fat rations for ruminants. II. Effects of fat added to corn plant material prior to ensiling on digestibility and voluntary intake of the silage. J. Anim. Sci. **36**: 397–406.

Kalscheur, K. F., Teter, B. B., Piperova, L. S. and Erdman, R. A. 1997. Effect of fat source on duodenal flow of *trans*-$C_{18:1}$ fatty acids and milk fat production in dairy cows. J. Dairy Sci. **80**: 2115–2126.

Kelly, M. L., Berry, J. R., Dwyer, D. A., Griinari, J. M., Chouinard, P. Y., Van Amburgh, M. E. and Bauman, D. 1998. Dietary fatty acid sources affect conjugated linoleic acid concentration in milk from lactating dairy cows. J. Nutr. **128**: 881–885.

Keeney, M. and Katz, I. 1962. On the probable origin of some milk fat acids in rumen microbial lipids. J. Am. Oil Chem. Soc. **39**: 198–201.

Kidwell, J. E., Bohman, V. R. and Hunter, J. E. 1954. Individual and group feeding of experimental beef cattle as influenced by hay maturity. J. Anim. Sci. **13**: 543–547.

Kim, H., Choi, S., Lee, H. J., Lee, J. H. and Choi, H. 2003. Suppression of fatty acid synthase by dietary polyunsaturated fatty acids is mediated by fat itself, not by peroxidative mechanism. J. Biochem. Molec. Biol. **36**: 258–264.

Krehbiel, C. R., McCoy, R. A., Stock, R. A., Klopfenstein, T. J., Shain, D. H. and Huffman, R. P. 1995. Influence of grain type, tallow level, and tallow feeding system on feedlot cattle performance. J. Anim. Sci. **73**: 2916–2921.

LaBrune, H. J., Drouillard, J. S., Hachmeister, K. A., Kropf, D. H. and Dikeman, M. E. 2002. Effects of tallow and ground flaxseed on sensory and color characteristics of ribeye steaks. Kansas Agric. Exp. Sta. Rep. Prog. **890**: 75–78.

Leizer, C., Ribnicky, D., Poulev, A., Dushenkov, S. and Raskin, I. 2000. The composition of hemp seed oil and its potential as an important source of nutrition. J. Nutr. Funct. Med. Foods **2**: 35–53.

MacDonald, H. B. 2000. Conjugated linoleic acid and disease prevention: A review of current knowledge. J. Am. Coll. Nutr. **19**: 111S-118S.

Maddock, T. D., Anderson, V. L., Berg, P. T., Maddock, R. J. and Marchello, M. J. 2003. Influence of level of flaxseed addition and time fed flaxseed on carcass characteristics, sensory panel evaluation, and fatty acid content of fresh beef. N. Dakota State Beef Res. Rep. [Online] Available: http://www.ag.ndsu.nodak.edu/carringt/livestock/Beef%20Report%2003/Flaxseed%20Addition.htm.

Markus, S. B., Wittenberg, K. M., Ingalls, J. R. and Undi, M. 1996. Production responses by early lactation cows to whole sunflower seed or tallow supplementation of a diet based on barley. J. Dairy Sci. **79**: 1817–1825.

McGuire, M. A., Duckett, S. K., Andrae, J. G., Giesy, J. G. and Hunt, C. W. 1998. Effect of high-oil corn on content of conjugated linoleic acid (CLA) in beef. J. Dairy Sci. **81**(Suppl. 1): 301.

Mir, P. S., Ivan, M., He, M. L., Pink, B., Okine, E., Goonewardene, L. A., McAllister, T. A., Weselake, R. and Mir, Z. 2003a. Dietary manipulation to increase conjugated linoleic acids and other desirable fatty acids in beef: A review. Can. J. Anim. Sci. **83**: 673–685.

Mir, P. S., McAllister, T. A., Zaman, S., Jones, S. D. M., He, M. L., Aalhus, J. L., Jeremiah, L. E., Goonwardene, L. A., Weselake, R. and Mir, Z. 2003b. Effect of dietary oil and vitamin E on beef cattle performance, carcass characteristics and meat quality. Can. J. Anim. Sci. **83**: 53–66.

Mustafa, A. F., McKinnon, J. J. and Christensen, D. A. 1999. The nutritive value of hemp meal for ruminants. Can. J. Anim. Sci. **79**: 91–95.

National Research Council. 1996. Nutrient requirements of beef cattle. 7th rev. ed. National Academy Press, Washington, DC. 242 pp.

Ntambi, J. M. 1999. Regulation of stearoyl-CoA desaturase by polyunsaturated fatty acids and cholesterol. J. Lipid Res. **40**: 1549–1558.

Palmquist, D. L. and Jenkins, T. C. 1980. Fat in lactation rations: review. J. Dairy Sci. **63**: 1–14.

Park, P. W. and Goins, R. E. 1994. In situ preparation of fatty acid methyl esters for analysis of fatty acid composition of foods. J. Food Sci. **59**: 1262–1266.

Parker, T. D., Adams, D. A., Zhou, K., Harris, M. and Yu, L. 2003. Fatty acid composition and oxidative stability of cold-pressed edible seed oils. J. Food Sci. **68**: 1240–1243.

Phipps, R. H., Bines, J. A. and Cooper, A. 1983. A preliminary study to compare individual feeding through Calan electronic feeding gates to group feeding. Anim. Prod. (Abstr.) **36**: 544.

Piperova, L., Teter, B. B., Sampugna, J., Yuraweca, M. P., Buckental, I. and Erdman, R. A. 2000. Dietary milk fat depression and *trans*-18:1 and CLA isomer distribution in milk of lactating cows. J. Anim. Sci. **78**(Suppl. 1): 277

Ramirez, R. M. and Zinn, R. A. 2000. Interaction of dietary magnesium level on the feeding value of supplemental fat in finishing diets for feedlot steers. J. Anim. Sci. **78**: 2072–2080.

Rule, D. D., Busboom, J. R. and Kercher, C. J. 1994. Effect of dietary canola on fatty acid composition of bovine adipose tissue, muscle, kidney, and liver. J. Anim. Sci. **72**: 2735–2744.

Scollan, N. D., Choi, N. J., Kurt, E., Fisher, M., Enser, M. and Wood, J. D. 2001. Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. Br. J. Nutr. **85**: 115–124.

Shah, M. A., Beauchemin, K. A. and Mir, P. S. 2004. Effects of sunflower (seeds or oil) supplementation of dairy cow diets on nutrient intake, lactational performance and fatty acid profile of milk. Can. J. Anim. Sci. **84**(Suppl 1): 104.

Smith, L. M., Dunkley, W. L., Franke, A. and Dairiki, T. 1978. Measurement of *trans* and other isomeric unsaturated fatty acids in butter and margarine. J. Am. Oil Chem. Soc. **55**: 257–261.

St. John, L. C., Young, C. R., Knabe, D. A., Thompson, G. T., Schelling, S. M., Grundy, S. M. and Smith, S. B. 1987. Fatty acid profiles and sensory and carcass traits of tissues from steers and swine fed an elevated monounsaturated fat diet. J. Anim. Sci. **64**: 1441–1447.

Van Soest, P. J., Robertson, J. B. and Lewis, B. A. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. **74**: 3583–3597.

Vernon, R. G. 1976. Effect of dietary fats on ovine adipose tissue metabolism. Lipids **11**: 662–669.

Warnick, V. D., Arave, C. W. and Mickelsen, C. H. 1977. Effects of group, individual, and isolated rearing of calves on weight gain and behavior. J. Dairy Sci. **60**: 943–953.

Weiss, M. F., Martz, F. A. and Lorenzen, C. L. 2004. Review: conjugated linoleic acid: historical context and implications. Prof. Anim. Sci. **20**: 118–126.

Wu, Z., Ohajuruka, O. A. and Palmquist, D. L. 1991. Ruminal synthesis, biohydrogenation, and digestibility of fatty acids by dairy cows. J. Dairy Sci. **74**: 3025–3034.

Zinn, R. A. 1988. Comparative feeding value of supplemental fat in finishing diets for feedlot steers supplemented with and without monensin. J. Anim. Sci. **66**: 213–227.

Zinn, R. A. 1989. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for steers: feedlot cattle growth and performance. J. Anim. Sci. **67**: 1029–1037.

Zinn, R. A. 1992. Comparative feeding value of supplemental fat in steam-flaked corn and steam-flaked wheat-based finishing diets for feedlot steers. J. Anim. Sci. **70**: 2959–2969.

Zinn, R. A. and Plascencia, A. 2004. Future of tallow as an ingredient in livestock diets. Pages 31–40 *in* Proceedings of the 25th Western Nutrition Conference, Saskatoon, SK.

Zinn, R. A. and Shen, Y. 1996. Interaction of dietary calcium and supplemental fat on digestive function and growth performance in feedlot steers. J. Anim. Sci. **74**: 2303–2309.