Asian-Aust. J. Anim. Sci.
Vol. 22, No. 8 : 1151 - 1159
August 2009

www.ajas.info

Effects of Flaxseed Diets on Performance, Carcass Characteristics and Fatty Acid Composition of Hanwoo Steers

Chong-min Kim, Jeong-hoon Kim[1], Young-kyoon Oh[2], Eun-kyu Park, Gyu-chul Ahn Gang-yeon Lee, Jung-il Lee and Keun-kyu Park*

Animal Resources Research Center, College of Animal Bioscience and Technology
Konkuk University, Seoul, 143-701, Korea

ABSTRACT : This study was conducted to determine the effects of dietary level of whole flaxseed (WFS; 0, 10 and 15%) on performance, carcass characteristics and fatty acid composition of serum and subcutaneous, perirenal, and intramuscular adipose tissues of Korean Hanwoo cattle. The daily gains were not different among treatments. Dietary inclusion of WFS decreased ($p<0.05$) feed intake but improved ($p<0.05$) feed conversion ratio (feed/gain). Backfat thickness and marbling score were increased ($p<0.05$) by dietary WFS. Carcass weight, dressing percentage, loin-eye area, and carcass yield and quality were not different among treatments. The proportion of C18:3 in serum and, to a lesser extent, in adipose tissues were increased ($p<0.01$) by dietary WFS, indicating that lipids from WFS escaped ruminal biohydrogenation. Animals fed WFS had lower proportions of saturated fatty acid (SFA; C14:0 and 16:0) and higher proportions of polyunsaturated fatty acids (PUFA; C18:2, 18:3, 20:2, 20:4, 20:5 and 22:6) in perirenal and intramuscular fat than animals fed diets without WFS, resulting in an increased PUFA/SFA ratio. Furthermore, feeding WFS increased ($p<0.01$) proportions of ω-3 and ω-6 fatty acids in intramuscular fat but decreased ($p<0.05$) the ω-6/ω-3 ratio. Relative treatment effects were similar between 10 and 15% WFS. Feeding WFS can effectively alter composition of adipose tissues with enhanced feed conversion ratio. (**Key Words** : Hanwoo Steer, Whole Flaxseed, Carcass Characteristics, Oilseeds, Fat Supplementation, Fatty Acid, Adipose Tissue)

INTRODUCTION

Recently, consumption of animal products containing low levels of saturated fats has been recommended because of a possible link between some saturated fatty acids (SFA) and cardiovascular diseases. As a result, attention has been directed towards producing animal products containing high levels of unsaturated fatty acids (UFA). However, it is more difficult to produce animal products with increased levels of UFA in ruminants than in non-ruminants because of biohydrogenation of dietary UFA by ruminal microorganisms. One approach altering fatty acid composition is to feed whole oilseeds that are naturally protected from the ruminal biohydrogenation by the seed coat. In fact, feeding whole oilseeds has been shown to prevent or lessen the adverse metabolic consequences of high-fat diets (White et al., 1987; Petit, 2002), and also improve the efficiency of energy utilization (Rule et al., 1989).

Physical characteristics of whole flaxseed (WFS), which are small, flat and oval-shaped (approximately 2×5 mm), may provide a means avoiding extensive mastication and ruminal biohydrogenation. Moreover, WFS is an excellent source of C18:3 which can be desaturated to other polyunsaturated fatty acids (PUFA). Previous studies demonstrated that feeding WFS to Hanwoo bulls and cows results in positive responses in animal performance (Kim et al., 2004a) and fatty acid composition of serum and adipose tissues (Kim et al., 2004b). However, similar feeding strategy has not been evaluated with Hanwoo steers. Therefore, the objective of this study was to investigate effects of dietary WFS on performance, carcass characteristics and fatty acid composition of Hanwoo steers.

* Corresponding Author: Keun-kyu Park. Tel: +82-2-450-3661, Fax: +82-2-455-1044, E-mail: kkpark@konkuk.ac.kr

[1] Animal Welfare Program, Faculty of Land and Food Systems, University of British Columbia, 2357 Main Mall, Vancouver, BC, V6T 1Z4, Canada.

[2] National Institute of Animal Science, Suwon, 441-706, Korea.
Received February 3, 2009; Accepted April 4, 2009

MATERIALS AND METHODS

Animals, treatments and management

Twenty-one Hanwoo steers (mean initial weight 497 kg±12, approximately 23 mo of age) were randomly assigned to one of three dietary treatments: i) WFS 0% (control), ii) WFS 10% and iii) WFS 15%. The control diet used flaxseed meal as a protein source to more clearly evaluate the effect of the flaxseed oil. Animals were housed by treatment group in three 4.3 m×7.4 m pens (7 steers/pen) with concrete floor in an enclosed barn. Diets containing equal levels of protein and Ca were fed for 120 days. All animals had *ad libitum* access to concentrates for the entire experimental period, whereas roughage (rice straw) intake was kept constant at 1.0 kg/animal/d. Animals were gradually adapted to their diets for the first 10 days and were fed twice daily (08:00 and 17:00) in equal portion. Steers had free access to water throughout the experiment.

Sample collection and measurement

Initial and final weights were the averages of two consecutive early-morning weights. Amount of feed offered were recorded and feed refusal was weighed by 2 wk interval to determine daily intake and feed/gain ratio. Representative samples of the experimental diets were collected weekly, composited at the end of experiment, dried and ground through a 1-mm screen with a Willey mill (Thomas Scientific, Model4, NJ, USA) for analyses. Jugular blood was obtained by venipuncture from the animals at 1 d before slaughtering, centrifuged at 2,200 ×*g* for 15 min to obtain serum, and stored at -20°C for analyses of cholesterol and fatty acid composition.

All animals were slaughtered at a commercial slaughterhouse. Immediately after postexsanguination, samples for analysis of fatty acid composition were taken from three adipose tissues. Samples of subcutaneous fat and longissimus muscle for intramuscular fat were taken from the 13th rib of the left side. The subcutaneous fat depot was separated at the natural seam between the two layers of fat. Perirenal fat was taken from the anterior portion of the kidney knob. Samples were vacuum-packaged in small plastic bags and transported to the laboratory on ice. Within approximately 2 h, the samples were stored at -20°C until analyzed.

Carcass measurements were obtained after chilling for 24 h at 2°C. Carcass yield and quality were determined at the 13th rib section from the left side of each carcass and graded by meat graders using the criteria provided by the Korean carcass grading system (NLCF, 1999). Carcass yield index (YI) was calculated from the following equation as described by the grading system:

$$YI = 65.834-(0.393\times\text{backfat thickness, mm}) +(0.088\times\text{longissimus muscle area, cm}^2) -(0.008\times\text{carcass wt., kg})$$

A score of carcass yield A represents "high (YI over 69.0)", a B "medium (YI between 66.0 and 69.0)" and a C "low (YI under 66.0)". Carcass quality (1 = high, 2 = medium, 3 = low) was determined by the following factors:

i) marbling score (1 = devoid, 7 = very abundant marbling);
ii) meat color (1 = very light cherry red, 7 = very dark red);
iii) fat color (1 = white, 7 = bright lemon yellow);
iv) texture (1 = good, 3 = bad);
v) maturity (1 = youthful, 3 = mature).

Chemical analyses

Concentrates, rice straw, and WFS were analyzed for moisture, crude protein (CP), ether extract, and ash according to AOAC (AOAC, 1990). Concentration of ash free neutral detergent fiber (aNDFom) was determined with a heat stable amylase and sodium sulphite according to methods of Van Soest et al. (1991), and level of ash free acid detergent fiber (ADFom) was determined according to procedure 973.18 of AOAC (1990). Nutrient composition of concentrates is presented in Table 1; composition of WFS and rice straw is shown in Table 2.

A homogenization and the Folch et al. (1957) procedure were employed to extract lipids from WFS and adipose tissue samples. Samples were homogenized three times in a 2:1 chloroform:methanol (vol/vol) mixture. Fatty acid composition in tissue lipid and serum was determined using GLC (HP5890A, Hewlett Packard Co., PA., USA) on a 30 m×0.25 mm Supelco Model SP 2330 (Supelco, Bellefonte, PA, USA) column. Initial temperature of the column was maintained at 150°C for 8 min, followed by an increase of 3°C/min to a final temperature of 195°C. The detector and injection port temperatures were held at 250°C and 200°C, respectively. Total cholesterol concentration in serum was measured using an ELISA commercial kit (Wako T-Cho E test; Wako Pure Chemical Co. Ltd., Osaka, Japan). Fatty acid composition of WFS is shown in Table 3.

Calculations and statistical analysis

Fatty acid data were summed by the class of fatty acid to obtain total SFA, UFA, monounsaturated (MUFA), and PUFA, and the ratios between SFA and the remaining classes of fatty acids were calculated. The differences in proportions of UFA, ω-3, and ω-6 fatty acids among adipose tissues were also evaluated. With the exception of the metabolically important ω-3 and ω-6 fatty acids, fatty acid percentages less than 1% are, in most case, not

Table 1. Ingredients and chemical composition of concentrate mixtures fed Hanwoo steers[1]

Items	Control	WFS[2] 10%	WFS 15%
Ingredients (%)			
Ground corn	37.50	36.50	35.50
Wheat grain	29.50	27.50	27.00
Wheat bran	5.00	5.00	5.00
Cottonseed meal	5.50	5.50	5.50
Rapeseed meal	4.00	4.00	4.00
Flaxseed meal	10.50	3.50	-
Flaxseed	-	10.00	15.00
Molasses	5.00	5.00	5.00
Limestone	1.00	1.00	1.00
Salt	0.50	0.50	0.50
Ca-phosphate	0.50	0.50	0.50
Vitamin-mineral mix[3]	1.00	1.00	1.00
Chemical composition (% dry matter)			
Dry matter (%)	87.46	87.11	87.73
Crude protein	18.63	18.23	18.34
Ether extract	2.53	4.38	4.96
Crude ash	8.14	8.01	7.86
Neutral detergent fiber	39.19	42.43	44.08
Acid detergent fiber	11.84	15.75	16.52

[1] Each steer had free access to water throughout the experiment.
[2] Whole flaxseed.
[3] Contains the following in kg of mixture: Vit. A 2,000,000 IU; Vit. D_3 400,000 IU; Vit E 1,500 IU; Mn 12,000 mg; Fe 12,000 mg; Zn 8,000 mg; Cu 1,000 mg; Co 1,000 mg; I 150 mg.

Table 2. Chemical composition of whole flaxseed (WFS) and rice straw fed to Hanwoo steers

Items (% dry matter)	WFS	Rice straw
Dry matter (%)	90.11	88.21
Crude protein	24.78	5.52
Ether extract	38.66	ND[1]
Neutral detergent fiber	46.42	73.89
Acid detergent fiber	35.82	49.81

[1] Not determined.

Table 3. Fatty acid composition of whole flaxseed fed to Hanwoo steers

Fatty acids	% total fatty acids
Myristic acid (C14:0)	0.22
Palmitic acid (C16:0)	6.55
Palmitoleic acid (C16:1)	0.24
Stearic acid (C18:0)	4.00
Oleic acid (C18:1)	25.98
Linoleic acid (C18:2)	14.89
Linolenic acid (C18:3)	47.08
Arachidonic acid (C20:4)	0.38
Others	0.66

reported, although all fatty acid percentages are included in totals of each class of fatty acids.

Data obtained from the experiment were analyzed by General Linear Models procedure of the SAS (2002; version 9.1) according to the following statistical model:

$$Y_{ij} = \mu+P_i+T_j+e_{ij}$$

where P and T are pen and treatment effects, respectively. Differences among means were determined by Duncan's multiple range test (Duncan, 1955) when F values were significant ($p<0.05$ or $p<0.01$).

RESULTS AND DISCUSSIONS

Performance

Body weights, daily weight gain, feed intake and feed/gain ratio of Hanwoo steers fed diets containing 0, 10 or 15% WFS are presented in Table 4. Initial and final body weights, and daily gains were not different among treatments. Daily feed intake was decreased ($p<0.05$) with dietary inclusion of WFS, but no effect of level of WFS was observed. Feed conversion ratio (feed/gain) was also improved ($p<0.05$) by dietary WFS without level effect.

Although 73 and 96% of more fat was supplied by WFS in WFS 10 and 15% diets, respectively, than in the control diet (Table 1), no different daily gain between treatments is probably due to decreased feed intakes. Thus, increased lipid in diet was not effect on animal performance. Fat addition to ruminant diets is known to interfere with fiber digestion and microbial populations in the rumen. As a result, feed intake of cattle fed diets containing high level of fat (8-10%) can be reduced (Bartle et al., 1994; Ramirez and Zinn, 2000; Felton and Kerley, 2004). However, additional fat derived from whole oilseeds had no negative effects on feed intake. Huerta-Leidenz et al. (1991) showed that dietary whole cottonseed level of 15 or 30% (3.3 and 6.6% additional fat) did not influence feed intake of steers. Similarly, feeding 10% (Petit, 2002) and up to 15%

Table 4. Effects of dietary whole flaxseed (WFS) on body weights, daily gain, feed intake and feed/gain ratio of Hanwoo steers

Items	Diets			
	Control	WFS 10%	WFS 15%	SEM[1]
Initial body weight (kg)	498.3	497.1	495.6	12.28
Final body weight (kg)	585.1	593.2	590.0	14.27
Daily gain (kg)	0.72	0.80	0.79	0.02
Daily feed intake (kg)	10.20[a]	9.87[b]	9.52[b]	0.59
Feed/gain ratio	13.78[a]	12.32[b]	12.10[b]	0.61

[a, b] Means in the same row with different superscripts differ significantly ($p<0.05$).
[1] Standard error of mean; n = 21.

(Kenelly and Khorasani, 1992) of the total DM as whole flaxseed had no negative effect on DM intake by dairy cows. This implies that whole oilseeds result in slower release of the oil in the rumen and, thereby, minimize potential adverse effect of fat on feed intake. Thus, it is unlikely that fat concentrations of 4.38 and 4.96%, in WFS 10 and 15%, respectively, caused the reduced feed intake in the present study. Feed conversion ratio was improved by inclusion of WFS due to decreased feed intake.

Carcass characteristics

Carcass yield and quality of Hanwoo steers fed diets containing 0, 10 or 15% WFS are shown in Table 5. Carcass weight, dressing percentage, loin-eye area and yield grade were not affected by the diet. Backfat thickness was increased by WFS ($p<0.05$) with no difference between 10 and 15% WFS. This result would be expected because feeding fat generally increases backfat thickness (Garrett et al., 1976; Bock et al., 1991; Lee et al., 2003). However, high-fat diets have not always increased backfat thickness. Kim et al. (2004a) previously reported that backfat thickness for Hanwoo bulls was decreased by 10 or 15% WFS addition, and that for cows tended to be decreased by WFS diet with increasing level of WFS. Other studies have also reported that supplemental fat has no effect (Brandt and Anderson, 1990; Maddock et al., 2006; Wang et al., 2006) on backfat thickness. This discrepancy may be attributed to difference in energy intake because backfat thickness is more related to energy intake than dietary energy concentration (Solomon et al., 1992).

Although meat color, fat color, firmness, maturity and quality grade were unaffected by treatment, dietary WFS increased ($p<0.05$) marbling score with no difference between levels. Considering that intakes were reduced by dietary WFS along with improved feed conversion ratio, this result shows that additional fat from WFS would have more efficiently been deposited in adipose tissues, especially in intramuscular fat, the most important fat depot in beef for human consumption. In the earlier study (Kim et al., 2004a), marbling score of Hanwoo bulls tended to increase as dietary level of WFS increased while that of cows tended to decrease. This may imply that fat derived from WFS is deposited in a different way between bulls and cows; the fat would have been deposited in intramuscular fat for bulls and subcutaneous and (or) internal depots (kidney, pelvic and heart) for cows.

Serum fatty acid composition

Fatty acid profiles and cholesterol concentration in serum of Hanwoo steers fed diets containing 0, 10 or 15% WFS are show in Table 6. Dietary WFS level elicited substantial changes in fatty acid composition of serum. Dietary WFS reduced proportions of SFA (C14:0, 16:0 and 18:0) and MUFA (C14:1 and 18:1) but increased proportions of PUFA (C18:2, 18:3, 20:2, and 20:4) except for C20:3. The higher proportion of PUFA with dietary WFS, particularly for C18:2 and 18:3 probably reflect increased absorption of these fatty acids from WFS. This would suggest that the natural protection of WFS encapsulated in the hard seed coat was adequate to prevent an extensive release of oil and thus biohydrogenation of PUFA in the rumen. Kim et al. (2004b) also reported that feeding WFS resulted in similar changes in fatty acid profiles of Hanwoo bulls and cows. Similarly, other studies have reported that dietary WFS decreased C18:1 but increased C18:2 and 18:3 in blood of dairy cattle (Goodridge et al., 2001; Petit, 2002).

Compared to the previous study by Kim et al. (2004b), the proportion of C18:2 in the serums of Hanwoo steers were substantially greater than those of Hanwoo bulls and

Table 5. Effects of dietary whole flaxseed (WFS) on carcass yield and quality of Hanwoo steers

Items	Diets			
	Control	WFS 10%	WFS 15%	SEM[1]
Carcass wt. (kg)	344.8	351.3	350.3	9.77
Dressing (%)	58.9	59.0	59.4	0.62
Backfat thickness (mm)	10.40[b]	13.00[a]	12.86[a]	1.77
Loin-eye area (cm^2)	75.00	79.00	77.00	2.80
Yield grade[2]	2.14	2.14	2.29	0.26
Marbling score[3]	2.55[b]	3.33[a]	3.14[a]	0.57
Meat color[4]	4.60	4.83	4.57	0.23
Fat color[5]	3.00	3.00	2.86	0.04
Firmness[6]	2.00	2.00	2.00	0.08
Maturity[7]	1.00	1.00	1.00	0.08
Quality grade[8]	2.00	2.24	2.43	0.21

[a, b] Means in the same row with different superscripts differ significantly ($p<0.05$).

[1] Standard error of mean; n = 21.

[2] A grade (yield index ≥69.0) = 3, B grade (66.0≤yield index<69.0) = 2, C grade (yield index<66.0) = 1.

[3] Marbling score standard: 1 = devoid, 7 = very abundant. [4] Meat score standard: 1 = very light cherry red, 7 = very dark red.

[5] Fat color standard: 1 = white, 7 = bright lemon yellow. [6] Firmness: 1 = firm, 3 = soft.

[7] Maturity: 1 = youthful, 3 = mature. [8] 1^+ grade (good) = 4, 1 grade = 3, 2 grade = 2, 3 grade (bad) = 1.

Table 6. Effects of dietary whole flaxseed (WFS) on fatty acid composition and cholesterol concentration of serums in Hanwoo steers (% total fatty acids)

Item[1]	Control	WFS 10%	WFS 15%	SEM[2]
Fatty acids				
C14:0	2.62^{A}	2.14^{B}	1.93^{C}	0.16
C14:1	0.53^{A}	0.31^{B}	0.33^{B}	0.05
C16:0	19.74^{A}	14.25^{B}	12.38^{C}	0.77
C16:1	2.09	2.12	2.29	0.09
C18:0	16.44^{a}	14.04^{b}	13.36^{c}	0.31
C18:1	15.73^{a}	14.01^{b}	14.62^{b}	0.62
C18:2 (ω-6)	32.14^{b}	37.99^{a}	38.92^{a}	1.65
C18:3 (ω-3, 6)	1.53^{B}	5.19^{A}	5.30^{A}	0.21
C20:2 (ω-6)	1.91^{b}	2.98^{a}	3.13^{a}	0.13
C20:3 (ω-3)	3.59^{a}	2.41^{b}	2.47^{b}	0.12
C20:4 (ω-6)	3.68^{c}	4.11^{b}	4.77^{a}	0.18
C20:5 (ω-3)	-	0.45^{b}	0.50^{a}	0.009
SFA	38.80^{A}	30.43^{B}	27.67^{C}	1.23
UFA	61.20^{B}	69.57^{A}	72.33^{A}	1.94
MUFA	18.35	16.44	17.24	1.14
PUFA	42.85^{B}	53.13^{A}	55.09^{A}	1.67
Ratios				
UFA/SFA	1.58^{C}	2.29^{B}	2.61^{A}	0.08
MUFA/SFA	0.47^{c}	0.54^{b}	0.62^{a}	0.02
PUFA/SFA	1.10^{C}	1.75^{B}	1.99^{A}	0.07
Cholesterol (mg/dl)	81.45^{c}	91.14^{b}	95.06^{a}	6.81

[A, B, C] Means in the same row with different superscripts differ significantly ($p<0.01$).
[a, b, c] Means in the same row with different superscripts differ significantly ($p<0.05$).
[1] SFA = Total saturated fatty acid; UFA = Total unsaturated fatty acid; MUFA = Total monounsaturated fatty acid; PUFA = Total polyunsaturated fatty acid.
[2] Standard error of mean; n = 21.

cows (Steers: 32.14, 37.99 and 38.92%, bulls: 20.11, 23.39 and 24.75%; cows: 20.15, 22.08 and 24.85% for 0, 10 and 15% WFS, respectively). In contrast, the proportion of C18:3 in the serums of steers were lower than those of bulls and cows (Steers: 1.53, 5.19 and 5.30%, bulls: 9.75, 17.31 and 19.01%; cows: 9.43, 18.86 and 19.46% for 0, 10 and 15% WFS, respectively). The reasons for this discrepancy remain unclear.

The concentration of serum cholesterol was increased ($p<0.05$) with increasing level of WFS. Supplementation of fat with various forms is known to increase blood cholesterol in lambs (Solomon et al., 1992), goats (Hirano et al., 2003), dairy cows (Garcia-Bojalil et al., 1998; Chen et al., 2002; Petit, 2002), and fattening cattle (Kita et al., 2003; Kim et al., 2004b). The present result shows that feeding WFS effectively provided intestinal-digestible fat.

Table 7. Effects of dietary whole flaxseed (WFS) on fatty acid composition of subcutaneous fat in Hanwoo steers (% total fatty acids)

Item[1]	Control	WFS 10%	WFS 15%	SEM[2]
Fatty acids				
C14:0	3.24	3.14	3.04	0.08
C14:1	2.43	2.28	2.53	0.09
C16:0	25.06^{a}	24.69^{ab}	23.72^{b}	0.21
C16:1	6.90^{b}	7.07^{b}	7.54^{a}	0.15
C18:0	6.30	6.23	6.11	0.17
C18:1	49.80	50.05	50.32	0.48
C18:2 (ω-6)	4.78	4.71	4.74	0.18
C18:3 (ω-3)	0.05^{B}	0.09^{A}	0.12^{A}	0.005
C18:3 (ω-6)	0.26^{B}	0.42^{A}	0.43^{A}	0.02
C20:2 (ω-6)	0.08^{B}	0.16^{A}	0.18^{A}	0.05
C20:3 (ω-3)	0.13^{a}	0.10^{b}	0.10^{b}	0.006
C20:4 (ω-6)	0.08	0.06	0.09	0.003
C20:4 (ω-3)	0.02^{B}	0.05^{A}	0.04^{A}	0.001
C20:5 (ω-3)	0.06^{c}	0.08^{b}	0.10^{a}	0.004
C22:6 (ω-3)	-	0.01	0.01	0.001
C24:1	0.24^{c}	0.26^{b}	0.29^{a}	0.009
SFA	34.73	34.17	32.98	0.52
UFA	65.27	65.83	67.02	0.73
MUFA	59.81	60.15	61.21	0.67
PUFA	5.46	5.68	5.81	0.11
ω-3 PUFA	0.27^{B}	0.33^{A}	0.37^{A}	0.04
ω-6 PUFA	5.20	5.35	5.44	0.07
Ratios				
UFA/SFA	1.88^{b}	1.93^{b}	2.03^{a}	0.02
MUFA/SFA	1.72^{b}	1.76^{b}	1.86^{a}	0.02
PUFA/SFA	0.16	0.17	0.11	0.005
ω-6/ω-3	19.27^{a}	16.21^{b}	14.71^{b}	0.17

[A, B] Means in the same row with different superscripts differ significantly ($p<0.01$).
[a, b, c] Means in the same row with different superscripts differ significantly ($p<0.05$).
[1] SFA = Total saturated fatty acid; UFA = Total unsaturated fatty acid; MUFA = Total monounsaturated fatty acid; PUFA = Total polyunsaturated fatty acid.
[2] Standard error of mean; n = 21.

Subcutaneous fatty acid composition

Compositional changes of fatty acids in subcutaneous fat of Hanwoo steers fed diets containing 0, 10 or 15% WFS are presented in Table 7. The three major fatty acids in subcutaneous fat were C18:1, 16:0 and 16:1 and their combined proportion was 82%, regardless of dietary treatments. The 15% WFS group had a lower proportion of C16:0 and a higher proportion of C16:1 ($p<0.05$) than others. Dietary WFS increased ($p<0.01$) the proportion of C18:3 (ω-3 and ω-6), 20:2 and 20:4 with no difference between 10 and 15% WFS. The proportion of C20:5 was increased ($p<0.05$) with increasing level of WFS. Similar changes in the proportion of these fatty acids were observed in Charolais steers fed 21% WFS (Scollan et al., 2001) and in Charolais heifers fed 15% flaxseed oil (Noci et al., 2007).

No differences were detected in the proportion of SFA, MUFA and PUFA. However, significant increase ($p<0.01$) in the proportion of ω-3 PUFA was observed for the steers fed WFS, regardless of the level. As a consequence, the ω-6/ω-3 ratio was decreased ($p<0.05$) by feeding WFS. Both UFA/SFA and MUFA/SFA ratios were increased ($p<0.05$)

by 15% WFS. Overall, the treatment effect on subcutaneous fat was relatively small in steers compared to that in bulls and cows in the previous study (Kim et al., 2004b).

Perirenal fatty acid composition

Fatty acid composition in perirenal fat of Hanwoo steers fed diets containing 0, 10 or 15% WFS is shown in Table 8. As observed in serum, proportions of SFA in perirenal fat were reduced ($p<0.05$ or 0.01) by dietary inclusion of WFS while those of C16:1, 18:1, 18:2, 18:3, 20:2 and 22:6 were increased ($p<0.05$ or 0.01); but no difference was detected between 10 and 15% WFS, except for C16:1. The proportion of UFA and the UFA/SFA ratio were increased ($p<0.05$) by feeding WFS, regardless of level of WFS. The higher proportion of UFA seems to be equally attributed to both MUFA and PUFA.

A higher proportion of ω-3 PUFA was observed ($p<0.01$) with 15% WFS only, whereas the proportion of ω-6 PUFA was increased ($p<0.01$) by both 10 and 15% WFS without the level effect. These results led to increased ($p<0.01$) ω-6/ω-3 ratio of dietary WFS treatments. Considering the fact that C18:3 is the major precursor of other ω-3 fatty acids and proportions of these ω-3 fatty acids were very low in perirenal fat, tissues from perirenal fat may not have had enough substrates and (or) enzymes for desaturation and elongation due to characteristics of internal fat depots.

The proportion of UFA was numerically lower in perirenal than in subcutaneous fat, whereas the reverse was also true for SFA. Most notable changes are increased proportion of C18:0 and proportions of C16:1 and 18:1 in perirenal fat compared to those in subcutaneous fat. These results agree with the observation that triglycerides from internal fat depots have a lower proportion of UFA compared to that from external fat depots, attributable to higher body temperature (Clemens et al., 1974) and lower desaturase activity (Chang et al., 1992) of internal adipose tissue.

Intramuscular fatty acid composition

Fatty acid composition in intramuscular fat of Hanwoo steers fed diets containing 0, 10 or 15% WFS is presented in Table 9. Similar changes in proportions of SFA and UFA in subcutaneous fat also occurred in intramuscular fat. Dietary WFS, regardless the level of WFS, decreased ($p<0.05$ or 0.01) the proportions of SFA (C14:0 and C16:0) while increased ($p<0.05$ or 0.01) the proportions of PUFA (C18:2, 18:3, 20:2, 20:4, 20:5 and 22:6). In contrast to the previous study (Kim et al., 2004b), the increased proportion of UFA seemed to be more attributable to the increased proportion of PUFA rather than MUFA. No significant effect of diet was observed in the proportion of MUFA. However, the ratio of MUFA/SFA was increased ($p<0.05$) due to the reduced proportion of SFA. Proportions of PUFA in the intramuscular fat of steers fed 10 and 15% WFS were increased ($p<0.01$) by 42.4 and 57.1%, respectively, compared with the control. Both ω-3 and ω-6 PUFA were elevated ($p<0.01$) by dietary WFS, regardless of the level of WFS. The ratio of ω-6/ω-3 was reduced ($p<0.05$) due to relatively greater increases in the proportion of ω-3 than those of ω-6 PUFA.

Increased proportions of C18:2 and 18:3 in the intramuscular fat of steers fed WFS probably result from similar changes in the same fatty acids of the serum. Greater proportions of PUFA rather than MUFA may imply that activities of desaturase in this tissue were high, based on the fatty acid compositions of flaxseed and serum. However, the effects of feeding WFS on the fatty acid profile of intramuscular fat are not consistent. The proportion of C18:2 was either increased by 10% ground

Table 8. Effects of dietary whole flaxseed (WFS) on fatty acid composition of perirenal fat in Hanwoo steers (% total fatty acids)

Item[1]	Control	WFS 10%	WFS 15%	SEM[2]
Fatty acids				
C14:0	3.88^{A}	3.01^{B}	2.86^{B}	0.12
C14:1	0.73^{c}	0.78^{b}	0.88^{a}	0.03
C16:0	27.53^{a}	24.15^{b}	22.89^{b}	0.61
C16:1	2.51^{b}	2.57^{b}	2.94^{a}	0.09
C18:0	18.95^{a}	17.89^{ab}	17.02^{b}	0.71
C18:1	41.25^{b}	44.82^{ab}	46.52^{a}	2.85
C18:2 (ω-6)	3.33^{B}	4.98^{A}	5.00^{A}	0.10
C18:3 (ω-3)	0.09^{B}	0.16^{A}	0.20^{A}	0.01
C18:3 (ω-6)	0.13^{B}	0.33^{A}	0.35^{A}	0.03
C20:2 (ω-6)	0.12^{b}	0.15^{a}	0.16^{a}	0.001
C20:3 (ω-3)	0.17^{A}	0.09^{B}	0.10^{B}	0.002
C20:4 (ω-6)	0.08	0.09	0.09	0.001
C20:4 (ω-3)	0.08^{A}	0.04^{B}	0.03^{B}	0.001
C20:5 (ω-3)	0.05^{c}	0.06^{b}	0.07^{a}	0.001
C22:6(ω-3)	0.08^{b}	0.11^{a}	0.10^{a}	0.003
C24:1	0.24	0.21	0.24	0.008
SFA	50.78^{a}	45.21^{b}	42.92^{b}	0.53
UFA	49.22^{b}	54.79^{a}	57.08^{a}	0.71
MUFA	45.09^{b}	48.78^{a}	50.98^{a}	0.66
PUFA	4.13^{b}	6.01^{a}	6.10^{a}	0.18
ω-3 PUFA	0.47^{B}	0.46^{B}	0.51^{A}	0.03
ω-6 PUFA	3.66^{B}	5.55^{A}	5.59^{A}	0.07
Ratios				
UFA/SFA	0.97^{b}	1.21^{a}	1.33^{a}	0.02
MUFA/SFA	0.89^{b}	1.08^{a}	1.19^{a}	0.01
PUFA/SFA	0.08^{b}	0.13^{a}	0.14^{a}	0.001
ω-6/ω-3	7.79^{B}	12.07^{A}	10.96^{A}	0.20

[A, B] Means in the same row with different superscripts differ significantly ($p<0.01$).

[a, b, c] Means in the same row with different superscripts differ significantly ($p<0.05$).

[1] SFA = Total saturated fatty acid; UFA = Total unsaturated fatty acid; MUFA = Total monounsaturated fatty acid; PUFA = Total polyunsaturated fatty acid.

[2] Standard error of mean; n = 21.

Table 9. Effects of dietary whole flaxseed (WFS) on fatty acid composition of intramuscular fat in Hanwoo steers (% total fatty acids)

Item[1]	Control	WFS 10%	WFS 15%	SEM[2]
Fatty acids				
C14:0	3.44^{A}	2.81^{B}	2.68^{B}	0.11
C14:1	1.31	1.36	1.33	0.08
C16:0	27.34^{a}	26.36^{ab}	25.55^{b}	0.38
C16:1	4.54^{b}	5.17^{a}	5.17^{a}	0.13
C18:0	10.87	9.85	9.71	0.27
C18:1	47.51	47.77	48.3	1.25
C18:2 (ω-6)	3.14^{B}	4.31^{A}	4.85^{A}	0.28
C18:3 (ω-3)	0.05^{B}	0.22^{A}	0.25^{A}	0.01
C18:3 (ω-6)	0.13^{B}	0.28^{A}	0.30^{A}	0.06
C20:2 (ω-6)	0.11^{b}	0.16^{a}	0.17^{a}	0.02
C20:3 (ω-3)	0.20	0.21	0.19	0.009
C20:4 (ω-6)	0.39^{B}	0.55^{A}	0.54^{A}	0.01
C20:4 (ω-3)	0.01^{B}	0.05^{A}	0.04^{A}	0.005
C20:5 (ω-3)	0.09^{b}	0.10^{b}	0.12^{a}	0.008
C22:6 (ω-3)	0.03^{B}	0.03^{B}	0.06^{A}	0.004
C24:1	0.35^{a}	0.30^{b}	0.27^{c}	0.01
SFA	41.84^{a}	39.17^{b}	38.08^{b}	0.56
UFA	58.16^{b}	60.83^{a}	61.92^{a}	0.61
MUFA	55.01	54.92	55.4	0.68
PUFA	4.15^{C}	5.91^{B}	6.52^{A}	0.12
ω-3 PUFA	0.38^{B}	0.61^{A}	0.66^{A}	0.05
ω-6 PUFA	3.77^{B}	5.28^{A}	5.81^{A}	0.09
Ratios				
UFA/SFA	1.39^{b}	1.55^{a}	1.63^{a}	0.06
MUFA/SFA	1.29^{b}	1.40^{a}	1.45^{a}	0.03
PUFA/SFA	0.10^{B}	0.15^{A}	0.17^{A}	0.004
ω-6/ω-3	9.93^{a}	8.66^{b}	8.80^{b}	0.18

$^{A, B, C}$ Means in the same row with different superscripts differ significantly ($p<0.01$).

$^{a, b, c}$ Means in the same row with different superscripts differ significantly ($p<0.05$).

[1] SFA = Total saturated fatty acid; UFA = Total unsaturated fatty acid; MUFA = Total monounsaturated fatty acid; PUFA = Total polyunsaturated fatty acid.

[2] Standard error of mean; n = 21.

flaxseed (LaBrune et al., 2008) and by 15% flaxseed oil (Noci et al., 2007), or decreased by 21.3% bruised WFS (Scollan et al., 2001). In the case of C18:3 (ω-3), increased proportion (Scollan et al., 2001; LaBrune et al., 2008) or no change (Noci et al., 2007) were observed. The intramuscular fatty acid composition is affected by several genetic and nutritional factors. Differences in breed, gender, feeding strategy and production system, together with processing method of flaxseed, may be involved. Further study to clarify these factors is required.

The C18:1 was the predominant fatty acid in bovine muscle and adipose tissue, comprising 48% of total fatty acids. Beef flavor has been reported to be positively correlated to C18:1 along with low percentages of SFA and PUFA (Dryden and Marchello, 1970; Larick and Turner, 1990; Mandell et al., 1998; Lee et al., 2003). Although the proportion of C18:1 was not increased by treatment in this study, the mean value throughout treatments (47.86%) is higher than those (31.0-37.1%) of other western breeds of cattle (Tanaka, 1985; Park and Yoo, 1994) and similar to that (49.4%) of Japanese Black Wagyu cattle (Zembayashi et al., 1995).

Intramuscular fat is the most important fat depots from a human health point of view because it cannot be removed before consumption. Furthermore, intramuscular fat content (marbling) is currently an important determinant of carcass value for markets in Korea. Because PUFA have the beneficial effects on human health (Williams, 2000), PUFA proportion in intramuscular fat rather than SFA is considered important. Feeding WFS increased the ratio of PUFA/SFA compared to the control diet in the present study. However, despite the increase in its ratio, values of the ratios (0.15 and 0.17 for 10 and 15% WFA, respectively) are below the recommended level (>0.45; Department of Health, UK, 1994). Considering that the PUFA/SFA ratio in various type of cattle fed flaxseed is generally less than 0.1 (Raes et al., 2004; Lee et al., 2008), the ratio in the current study is nonetheless higher than other studies. It has been reported that the fat concentration of muscle has a major influence on the PUFA/SFA ratio because PUFA are mainly present in the phospholipid fraction, which is diluted by the gradual accretion of neutral lipid fraction as animals deposit body fat (Noci et al., 2007). Scollan et al. (2003) suggested that the amount of intramuscular fat is inversely related to the PUFA/SFA ratio, mainly observed in meat of ruminants.

Besides the beneficial effects of PUFA for human health (Williams, 2000), ω-3 fatty acids and the ω-6/ω-3 ratio have received much attention for health promoting effects of ω-3 fatty acids (Alexander, 1998; Belch and Muir, 1998; Harbige, 1998). In the current study, feeding WFS contributed to a high daily intake of C18:3, regardless of the level of WFS, and increased both the ω-3 and ω-6 fatty acids but decreased the ω-6/ω-3 ratio. The ratio in this study was 9.93, 8.66 and 8.80 for control, 10 and 15% WFS, respectively, but is higher than the recommended level (<5.90; Department of Health, UK, 1994). Generally, the ratio of finishing beef cattle on grazing pasture is less than 2.0, while the ratios of animals fed concentrate ranged from 6.0 to 10.0 (Marmer et al., 1984; Sañudo el al., 2000, Scollan et al., 2001; Maddock et al., 2006).

Overall, dietary WFS induced substantial changes in fatty acid composition of adipose tissues. However, the differences between 10 and 15% WFS were not observed in this study. This may imply that the magnitude of change is similar for 10 and 15% WFS groups.

IMPLICATIONS

Feeding whole flaxseed at 10 and 15% of diets reduced feed intake but improved feed conversion ratio in Korean Hanwoo steers. Dietary whole flaxseed decreased saturated fatty acids and the ratio of ω-6/ω-3 fatty acids and increased PUFA and PUFA/SFA ratio. These changes can be considered beneficial to the health of beef consumers.

ACKNOWLEDGMENTS

This work was supported by grants from the Science and Technology (MEST) of Korea to the Korea Institute of Oriental Medicine (G07080, K08141) and by Biogreen 21 (#20070303034044). The authors would like to thank Dr. D. M. Veira, Agriculture and Agri-Food Canada, Agassiz, BC, for helpful discussion and linguistic revision of the manuscript.

REFERENCES

Alexander, J. W. 1998. Immunonutrition: The role of ω-3 fatty acids. Nutr. 14:627-633.

AOAC. 1990. Official method of analysis. 15th edn. Association of Official Analytical Chemists, Washington, DC. pp. 152-157.

Bartle, S. J., R. L. Preston and M. F. Miller. 1994. Dietary energy source and density: Effects of roughage source, roughage equivalent, tallow level, and steer type on feedlot performance and carcass characteristics. J. Anim. Sci. 72:1943-1953.

Belch, J. J. F. and A. Muir. 1998. n-6 and n-3 essential fatty acids in rheumatoid arthritis and other rheumatic conditions. Proc. Nutr. Soc. 57:563-569.

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

Brandt, R. T. and S. J. Anderson. 1990. Supplemental fat sources affect feedlot performance and carcass traits of finishing yearling steers and estimated diet net energy value. J. Anim. Sci. 68:2208-2216.

Chang, J. H. P., D. K. Lunt and S. B. Smith. 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.

Chen, K-J., D-F. Jan, P. W-S. Chiou and D-W Yang. 2002. Effects of dietary heat extruded soybean meal and protected fat supplement on the production, blood and ruminal characteristics of Holstein cows. Asian-Aust. J. Anim. Sci. 15:821-827.

Clemens, E., W. Woods and V. Arthaud. 1974. The effect of feeding unsaturated fats as influenced by gelatinized corn and by the presence or absence of rumen protozoa. II. Carcass lipid composition. J. Anim. Sci. 38:640-645.

Department of Health, UK. 1994. Report on health and social subjects No. 46. Nutritional aspects of cardiovascular disease. HMSO, London, UK.

Dryden, F. D. and J. A. Marchello. 1970. Influence of total lipid and fatty acid composition upon the palatability of three bovine muscles. J. Anim. Sci. 31:36-41.

Duncan, D. B. 1955. Multiple range and multiple F test. Biometrics 11:1-4.

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

Folch, J., M. Lees and G. H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.

Garcia-Bojalil, C. M., C. R. Staples, C. A. Risco, J. D. Savio and W. W. Thatcher. 1998. Protein degradability and calcium salts of long-chain fatty acids in the diets of lactating dairy cows: Productive responses. J. Dairy Sci. 81:1374-1384.

Garrett, W. N., Y. T. Yang, W. L. Dunkley and L. M. Smith. 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.

Goodridge, J., J. R. Ingalls and G. H. Crow. 2001. Transfer of omega-3 linolenic acid and linoleic acid to milk fat from flaxseed or linola protected with formaldehyde. Can. J. Anim. Sci. 81:525-532.

Harbige, L. S. 1998. Dietary n-6 and n-3 fatty acids in immunity and autoimmune disease. Proc. Nutr. Soc. 57:555-562.

Hirano, Y., H. Yokota and K. Kita. 2003. Increase in plasma HDL-cholesterol concentration in goats fed sesame meal is related to ether extract fraction included in the meal. Asian-Aust. J. Anim. Sci. 16:511-514.

Huerta-Leidenz, N. O., H. R. Cross, D. K. Lunt, L. S. Pelton, J. W. Savell and S. B. Smith. 1991. Growth, carcass traits and fatty acid profiles of adipose tissues from steers fed whole cottonseed. J. Anim. Sci. 69:3665-3672.

Kenelly, J. J. and R. G. Khorasani. 1992. Influence of flaxseed feeding on the fatty acid composition of cow's milk. In: Proceedings of the 54th Flax Inst. Conf. North Dakota St. Univ. Fargo. pp. 99-105.

Kim, C. M., J. H. Kim, T. Y. Chung and K. K. Park. 2004a. Effects of Flaxseed diets on fattening response of Hanwoo cattle: 1. Performance and carcass characteristics. Asian-Aust. J. Anim. Sci. 17:1241-1245.

Kim, C. M., J. H. Kim, T. Y. Chung and K. K. Park. 2004b. Effects of Flaxseed diets on fattening response of Hanwoo cattle: 2. Fatty acid composition of serum and adipose tissues. Asian-Aust. J. Anim. Sci. 17:1246-1254.

Kita, K., M. Oka and H. Yokota. 2003. Dietary fatty acid increases body weight gain without a change in rumen fermentation in fattening cattle. Asian-Aust. J. Anim. Sci. 16:39-43.

LaBrune, H. J., C. D. Reinhardt, M. E. Dikeman and J. S. Drouillard. 2008. Effects of grain processing and dietary lipid source on performance, carcass characteristics, plasma fatty acids, and sensory properties of steaks from finishing cattle. J. Anim. Sci. 86:167-172.

Larick, D. K. and B. E. Turner. 1990. Flavour characteristics of forage- and grain-fed beef as influenced by phospholipid and fatty acid compositional differences. J. Food Sci. 55:312-317.

Lee, H-J., S. C. Lee, Y. G. Oh, K. H. Kim, H. B. Kim, Y. H. Park, H. S. Chae and I. B. Chung. 2003. Effects of rumen protected oleic acid in the diet on animal performances, carcass quality and fatty acid composition of Hanwoo steers. Asian-Aust. J. Anim. Sci. 16:1003-1010.

Lee, S. K., Panjono, S. M. Kang, Y. B. Jung, T. S. Kim, I. S. Lee, Y. H. Song and C-G Kang. 2008. Effects of tethering and loose housing on the meat quality of Hanwoo bulls. Asian-Aust. J. Anim. Sci. 21:1807-1814.

Maddock, T. D., M. L. Bauer, K. B. Koch, V. L. Anderson, R. J. Maddock, G. Barceló-Coblijn, E. J. Murphy and G. P. Lardy. 2006. Effect of processing flax in beef feedlot diets on performance, carcass characteristics, and trained sensory panel ratings. J. Anim. Sci. 84:1544-1551.

Mandell, I. B., J. G. Buchanan-Smith and C. P. Campbell. 1998. Effects of forage vs. grain feeding on carcass characteristics, fatty acid composition, and beef quality in Limousin-cross steers when time on feed in controlled. J. Anim. Sci. 76:2619-2630.

Marmer, W. N., R. J. Maxwell and J. E. Williams. 1984. Effects of dietary regimen and tissue site on bovine fatty acid profiles. J. Anim. Sci. 59:109-121.

NLCF. 1999. Korean carcass grading standard. National Livestock Co-operatives Federation, Seoul, Korea.

Noci, F., P. French, F. J. Monahan and A. P. Moloney. 2007. The fatty acid composition of muscle fat and subcutaneous adipose tissue of grazing heifers supplemented with plant oil-enriched concentrates. J. Anim. Sci. 85:1062-1073.

Park, B. S. and I. J. Yoo. 1994. Comparison of fatty acid composition among imported beef, Holstein steer beef and Hanwoo beef. Kor. J. Anim. Sci. 36(1):69-75.

Petit, H. V. 2002. Digestion, milk production, milk composition and blood composition of dairy cows fed whole flaxseed. J. Dairy Sci. 85:1482-1490.

Ponnampalam, E. N., G. R. Trout, A. J. Sinclair, A. R. Egan and B. J. Leury. 2001. Comparison of the color stability and lipid oxidative stability of fresh and vacuum packaged lamb muscle containing elevate omega-3 and omega-6 fatty acid levels from dietary manipulation. Meat Sci. 58:151-161.

Raes, K., S. De Smet and D. Demeyer. 2004. Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: a review. Anim. Feed Sci. Technol. 113:199-221.

Ramirez, J. E. and R. A. Zinn. 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. C., W. H. Wu, J. R. Busboom, F. C. Hinds and C. J. Kercher. 1989. Dietary canola seeds alter the fatty acid composition of bovine subcutaneous adipose tissue. Nutr. Rep. Int. 39:781.

Sanũdo, C., M. E. Enser, M. M. Campo, G. R. Nute, G. I. Maria, I. Sierra and J. D. Wood. 2000. Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain. Meat Sci. 54:339-346.

SAS Institute. 2002. SAS® User's guide: Statistics. Version 9.1 Edition. Statistical Analysis Systems Institute Inc., Cary, NC.

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

Scollan, N. D., M. Enser, S. K. Gulati, I. Richardson and J. D. Wood. 2003. Effects of including a ruminally protected lipid supplement in the diet on the fatty acid composition of beef muscle. Br. Nutr. 90:709-716.

Solomon, M. B., G. P. Lynch and D. S. Lough. 1992. Influence of dietary palm oil supplement on serum lipid metabolites, carcass characteristics and lipid composition of carcass tissues of growing ram and ewe lambs. J. Anim. Sci. 70:2746-2751.

Tanaka, S. 1985. Chemical studies on the adipose tissues and muscle lipids of fattening beef cattle IV. Fatty acid composition and their interrelationships of subcutaneous, intermuscular and abdominal adipose tissues form three beef breeds. Japanese J. Dairy Food Sci. 34(4):A91-A102.

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

Wang, J. H., S. H. Choi, K. W. Lim, K. H. Kim and M. K. Song. 2006. Effects of the mixed oil and monensin supplementation, and feeding duration of supplements on c9,t11-CLA contents in plasma and fat tissues of Korean native (Hanwoo) steers. Asian-Aust. J. Anim. Sci. 19:1464-1469.

White, B. G., J. R. Ingalls, H. R. Sharman and J. A. McKirdy. 1987. The effects of whole sunflower seeds on the flow of fat and fatty acids through the gastrointestinal tract of cannulated Holstein steer. Can. J. Anim. Sci. 67:447-459.

Williams, C. M. 2000. Dietary fatty acids and human health. Ann. Zootechonol. 49:165-180.

Zembayashi, M., K. Nishimura, D. K. Lunt and S. B. Smith. 1995. Effect of breed type and sex on the fatty acid composition of subcutaneous and intramuscular lipids of finishing steers and heifers. J. Anim. Sci. 73:3325-3332.