Technical

Fatty Acids of Adipose Tissue, Plasma, Muscle and Duodenal Ingesta of Steers Fed Extruded Soybeans

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Effects of feeding a high-energy diet that contained extruded soybeans on fatty acid composition of lipids of adipose tissue, skeletal muscle and plasma were determined for 18 Angus steers. Steers weighing an average of 309 kg were fed either a control diet or a diet containing 14.3% extruded soybeans and 6% fat until they weighed 474 kg. A third group was fed the control diet for the first half of the experiment and the soybean-containing diet for the rest of the experiment. Samples of blood, muscle (*M. trapezius*) and subcutaneous adipose tissue were obtained at 309, 368 and 427 kg of body weight; steers were slaughtered at 474 kg body weight, and samples of subcutaneous and perirenal adipose tissues, *M. longissimus* and blood were obtained. The lipids of subcutaneous adipose tissue taken at slaughter of all steers fed full-fat, extruded soybeans contained 24% more 18:2 and 18:3 than did those of steers fed the control diet. Extruded soybeans also caused an increase in 18:3 but only a slight increase in 18:2 in perirenal adipose tissue. The proportion of unsaturated fatty acids of lipids in *M. trapezius* increased slightly with dietary soybeans, whereas that of *M. longissimus* was not affected. Lipids of blood plasma of soybean-fed steers contained a greater proportion of 18:2 and 18:3 and concomitantly less 14:0, 15:0, 16:1 and 17:0. Results indicate that feeding steers enough extruded soybeans to raise the fat content of the diet to 6% increases the proportion of polyunsaturated fatty acids of tissue lipids of cattle, and that this altered composition results from an increased amount of these fatty acids being available for absorption by the small intestine.

Lipids of ruminant adipose tissue contain relatively large proportions of saturated fatty acids (1), even though fatty acids of typical ruminant feeds are mostly unsaturated (2). Microbial hydrogenation in the rumen is responsible for the extensive saturation of fatty acids of feed lipids (3). Formaldehyde treatment of polyunsaturated vegetable oil (4,5), however, greatly decreases the susceptibility to ruminal biohydrogenation. Accordingly, consumption of formaldehyde-protected oils increased the unsaturated fatty acid content of lamb (6), veal (7) and beef (1).

Simply increasing the fat content of diets for dairy cows increased the unsaturated fatty acid content of milk (8,9). Similarly, supplementing diets of sheep with full-fat soy flour resulted in increased proportions of 18:2 in lipids of rump, shoulder, kidney and omental adipose tissues (10). Dryden et al. (11) found that supplementation of beef cattle diets with safflower oil to a concentration of 6% increased 18:2 in subcutaneous adipose tissue. Research indicates, therefore, that the polyunsaturated fatty acid content of milk and tissue can be increased by feeding diets supplemented with highly polyunsaturated fats.

In addition to amount of unsaturated fat, energy density of the diet also influences fatty acid composition of adipose tissue lipids of cattle (12-14). High-concentrate diets support rumen microbial populations that are less active in biohydrogenation of polyunsaturated fatty acids (12).

Heat treatment of soybeans decreases protein solubility in the rumen of cattle, allowing for more postruminal digestion of soybean protein (15). Whether the protection afforded the protein of heat-treated soybeans from rumen microbial metabolism is associated with protection from biohydrogenation of soybean lipids has not been investigated. Our primary objective, therefore, was to determine if feeding a diet that contained enough full-fat, extruded soybeans to reach 6% dietary fat (the practical upper limit of dietary fat for finishing beef cattle) would affect the fatty acid composition of lipids from adipose tissue, muscle and blood plasma of finishing beef steers. A secondary objective was to determine the extent of ruminal biohydrogenation.

MATERIALS AND METHODS

Experimental design. Eighteen purebred Angus steers were divided on the basis of body weight into two groups of nine steers. Steers of each group then were allotted randomly to one of three dietary treatments. Each treatment was imposed on two open-air pens of three steers each and consisted of (i) a control diet (C); (ii) a diet containing enough full-fat, extruded soybeans to increase the fat content to ca. 6% (S), and (iii) the control diet fed for the first half of the experiment and then changed to the soybean-containing diet for the rest of the experiment (CS). Diet compositions are shown in Table 1. Diets were fed until steers weighed an average of 474 kg. Allotment of cattle to diets was replicated by subdividing each treatment group into two groups of three "lightweight" and three "heavyweight" steers. Heavyweight cattle weighed approximately 45 kg more than did lightweight cattle at initiation of the trial. Heavyweight cattle attained slaughter weight in November and the lightweight group in January.

Biopsies of adipose tissue, muscle and blood were obtained from each steer when steers of each weight group weighed an average of 309 (time 1), 368 (time 2) and 427 kg (time 3). Samples also were obtained at slaughter when the average body weight of steers was 474 kg (time 4). The steers alloted to the CS treatment, therefore, were fed the control diet during sampling times 1 and 2 and the soybean-containing diet during the last two sampling times. This CS treatment was

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imposed so that the effect of length of time that steers were fed the soybean-containing diet could be determined.

Feeding and management. All steers were offered their diets and water ad libitum. Concentrates and corn silage were combined and fed in two equal portions at 0800 and 1500 hr. Every 14 days, steers were weighed after an overnight stand without feed or water, and samples of each feed were taken every 28 days. Individual feed samples were combined and analyzed for content of crude protein and ether extract (16). At the beginning and at 60-day intervals, each steer was implanted with Synovex-S. (Each implant contained 200 mg progesterone and 20 mg estradiol benzoate. Syntex Agribusiness Inc., Des Moines, Iowa.)

Tissue sampling. Biopsies of subcutaneous adipose tissue and *M. trapezius* (2 to 3 g each) were obtained after lidocaine local anesthesia in an area of the 8th rib and approximately 10 cm from the midline of the back. The second biopsy was obtained from the opposite side, and the third biopsy from the same side as the first but approximately 8 cm caudal to the first incision. After each biopsy, steers were given an intramuscular injection of Combiotic. (Contained 200,000 U procaine penicillin G and 250 mg dehydrostreptomycin per ml. Pfizer, Inc., New York, New York.) Adipose tissue and *M. trapezius* biopsies were placed immediately into Ca^{+2}-free Krebs-Ringer bicarbonate buffer, pH 7.4, at 37 C (17) until they could be stored at −20 C under nitrogen for later analyses.

All steers were slaughtered by stunning followed by exsanguination. Immediately after exsanguination, subcutaneous adipose tissue was dissected from an area about 8 cm caudal to the scar of the second biopsy incision and placed into Ca^{+2}-free Krebs-Ringer bicarbonate buffer, pH 7.4, at 37 C (17). Perirenal adipose tissue was sampled and placed into the same buffer. Adipose tissue samples then were stored at −20 C under nitrogen for later analyses. After each steer carcass had hung four days in a room maintained at 4 C, a 3.2-cm thick cross-sectional cut of the *M. longissimus* was removed from the 11th rib section, wrapped to prevent evaporative losses and stored at −20 C for later analyses.

Jugular vein blood was collected by venipuncture into tubes that contained disodiumethylenediaminetetracetate as an anticoagulant (1.5 mg/ml of blood) on each biopsy day and again 3 to 5 days before slaughter. Plasma was separated by centrifugation at 7,000 × g for 20 min.

Duodenal ingesta. A separate study was conducted to determine the extent of biohydrogenation of fats in diets fed during the afore described experiment. Duodenal cannulas were installed into three Holstein steers at an average body weight of 124 kg (18). A Latin-square design was employed such that steers were fed each of these three diets sequentially for three weeks: control diet (Table 1), diet that contained 6% fat from added extruded soybeans (Table 1) and a third diet that contained 9% fat from additional extruded soybeans. Extruded soybeans replaced an equal weight of corn of the high-fat diet of Table 1 to increase the dietary fat to 9%.) Duodenal contents were collected from all steers weeks after feeding each diet. At every collection, 500 ml of duodenal contents were obtained one hr after feeding; collections were repeated 2 days later. Each sample was stored at −20 C under nitrogen for later analyses. At each collection time, samples of each concentrate and corn silage were obtained for later analyses of fatty acid composition.

TABLE 1

Composition of Experimental Diets

Item[a]	Diet	
	Control	High-fat
Cracked corn, %	57.7	54.2
Soybean meal, %	10.8	—
Soybeans, %[b]	—	14.3
Molasses, %	2.2	2.2
Corn silage, %	27.8	27.6
Ground limestone, %	.70	.70
Dicalcium phosphate, %	.15	.15
Trace mineral salt, %[c]	.45	.45
Vitamin and mineral mix, %[d]	.20	.20
Crude protein, %[e]	12.9	13.1
Ether extract, %[e]	3.28	5.81
Metabolizable energy, Mcal/kg[f]	3.01	3.03

[a]Dry-matter basis.
[b]Extruded soybeans donated by Triple "F" Inc., Des Moines, Iowa.
[c]Contained, as a %: NaCl, 98; $MnSO_4$, .28; MnO, .20; $FeSO_4 \cdot H_2O$, .61; CuO, .04; $CoCO_3$, .07; $Ca(IO_3)_2$, .01; ZnO, .01.
[d]Contained: MnO, 5.70%; CuO, .84%; $CoCO_3$, .02%; ZnO, 5.49%; $Ca(IO_3)_2$, .12%; $CaCO_3$, 16.5%; FeO, 1.49%; $FeCO_3$, 2.41%; KCl, 10.4%; Rumensin-60, 13.1%; menadione dimethylpyrimidinol bisulfite, .054%; cholecalciferol, 35.8 μg/g; retinyl acetate, .49 mg/g; dl-α-tocopherol acetate, .72 mg/g; carriers, 43.7%.
[e]Determined by using procedures described in AOAC (16).
[f]Calculated from reported values (36) for cracked corn, soybean meal, soybeans, cane molasses and corn silage.

Lipid analyses. A 3.2- × 4- × 10-cm core was removed from the center of each *M. longissimus* sample; each core was ground, mixed and lyophilized. Equal volumes of duodenal ingesta samples from each Holstein steer from each diet were combined and lyophilized; feed samples obtained at each ingesta collection also were lyophilized.

Lipids were extracted from duplicate samples of adipose tissue (.5 g), *M. trapezius* (2 g), *M. longissimus* (1 g dry matter), plasma (4 ml), duodenal ingesta (1 g dry matter) and feed (2 g dry matter) as described by Bligh and Dyer (19). Lipid extracts form *M. trapezius* and blood plasma from the three steers in each pen at each sampling time were pooled.

Fatty acid methyl esters were prepared by incubating up to 100 mg of each lipid residue in 3 ml of 14% boron trifluoride in methanol for 12 hr at 70 C (20). Composition of the fatty acid methyl esters was determined using a Perkin-Elmer 900 gas chromatograph equipped with a 1.83 m × .32 cm (inside diameter) metal column packed with 10% diethylene glycol succinate on 80/100 Supelcoport (Supelco, Inc., Bellefonte, Pennsylvania) and a flame ionization detector. Injector temperature was 250 C, column temperature was 175 C and flow rate of carrier nitrogen gas was 20 ml/min. Weight percentage of each fatty acid was calculated directly with a Shimadzu C-R1B integrator.

Identity of fatty acids was determined by comparing retention times with those of fatty acid methyl ester standards. Coefficients of variation (%) for fatty acid analyses were as follows: 14:0, 1.65; 15:0, 2.97; 16:0, .99; 16:1, .60; 17:0, 3.09; 18:0, .79; 18:1, 2.03; 18:2, 1.12; 18:3, 5.47.

Statistical analyses. Differences between treatment means were determined by analysis of variance (21). For the Angus steer trial, data within each sampling time were analyzed separately. For adipose tissue and *M. longissimus*, each steer served as an experimental unit; for plasma and *M. trapezius*, each pen served as an experimental unit. Effect of sampling time on adipose tissue fatty acid composition was tested using the mean square for treatment × block × sampling time interaction as the error term. For muscle and plasma fatty acids, sampling times served as block and were tested using the mean square for treatment × block interaction as the error term. Duncan's multiple range test was used to locate differences between treatment means at the .05 level of significance. All statistical analyses were conducted using the Statistical Analysis System (22).

RESULTS AND DISCUSSION

The major objective was to determine the effect of increased dietary fat from full-fat, extruded soybeans on fatty acid composition of lipids in adipose tissue, skeletal muscle and blood plasma of beef cattle during growth. Secondarily, fatty acid compositions of feeds and duodenal ingesta of steers fed the experimental diets will be related to fatty acid composition of the aforementioned tissues.

With regard to feed intake, no differences ($P > .05$) were observed for the three dietary groups; intake averaged 9.60 kg/day. Steers were fed their diets for 126 days.

Subcutaneous adipose tissue. Effect of dietary extruded soybeans on composition of fatty acids from subcutaneous adipose tissue of growing steers is presented in Table 2. No treatment differences were observed at sampling times 1 and 2. At sampling time 3, adipose tissue lipids of S steers had a greater ($P < .05$) proportion of 18:3 than did those of C steers. The proportion of 18:3 of CS steers was intermediate but not different ($P > .05$) from that of either C or S steers. Although statistically nonsignificant, the proportion of 18:2 in S steers was 23% greater than that of C steers at time 3. At sampling time 4 (slaughter), steers of treatment S had a 23% greater proportion of 18:2 and 11% more 18:3 than did C steers, and CS steers had an 11% greater proportion of 18:2 and 24% more 18:3 than did C steers. Diet had no significant effect on proportions of other fatty acids, although proportions of 16:0 and 18:0 tended to decrease and 18:1 to increase in

TABLE 2

Fatty Acid Composition of Subcutaneous Adipose Tissue Lipids of Steers Fed the Control or High-Fat Diets

	Fatty acid[a]								
Treatment[b]	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Sampling Time = 1[c]									
C[d]	4.58	1.90	30.0	5.76	1.27	13.0	39.2	2.44	.40
CS	4.55	1.97	29.3	5.23	1.23	14.7	39.0	2.38	.45
S	4.57	1.95	28.9	4.92	1.50	14.9	38.6	2.70	.46
SD[e]	.76	.30	2.23	.68	.21	1.48	2.33	.63	.11
Sampling Time = 2									
C	4.52	1.98	28.5	5.74	1.30	12.5	41.0	2.60	.44
CS	4.43	1.90	28.7	5.62	1.33	13.0	40.7	2.50	.44
S	4.67	1.92	29.3	5.15	1.25	13.3	39.9	2.92	.51
SD	4.03	.36	2.67	.92	.33	1.96	3.14	.60	.11
Sampling Time = 3									
C	4.36	2.10	28.8	6.46	1.22	10.8	41.7	2.88	.49[g]
CS	4.20	1.98	27.9	5.93	1.14	11.9	42.1	3.02	.53[f,g]
S	4.03	1.87	27.8	5.07	1.17	12.8	42.0	3.55	.64[f]
SD	.65	.39	1.88	1.07	.24	1.53	2.16	.57	.09
Sampling Time = 4	4.14								
C	3.85	1.94	27.8	6.36	1.16	10.6	42.7	3.04	.54
CS	4.08	1.97	26.7	5.60	1.00	10.4	43.4	3.57	.67
S	.73	2.33	27.5	6.43	1.07	9.80	43.5	3.75	.60
SD		.33	2.21	.95	.23	1.21	2.48	.63	.13

[a]Values are weight percentages of all fatty acids observed.

[b]C, control diet fed throughout the experiment; CS, control diet fed during sampling times 1 and 2 and then fed the soybean supplemented diet, beginning at an average body weight of 386 kg, during sampling times 3 and 4; S, soybean supplemented diet fed throughout the experiment.

[c]Sampling times: 1 occurred at an average body weight of 309 kg, 2 at 368 kg, 3 at 427 kg and 4 at 474 kg.

[d]n=5; approximately 4 wk after the start of the experiment one steer was removed from treatment C because of chronic respiratory illness. For both treatments CS and S, n=6.

[e]Standard deviation.

[f,g]Means with different superscripts in columns within sampling time differ ($P < .05$).

TABLE 3

Fatty Acid Composition of Perirenal Adipose Tissue Lipids—Effect of Diet and Comparison with Composition of Subcutaneous Adipose Tissue[a]

	Fatty acid[b]								
Item	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Treatment[c]									
C	3.92	.66[f]	28.8	3.04	1.28	24.5	34.1	2.34	.37[f]
CS	3.77	.95[e]	27.3	3.10	1.10	24.3	34.3	3.30	.51[e]
S	3.80	.69[e,f]	27.4	2.87	1.19	25.6	33.8	3.12	.57[e]
SD[d]	.66	.20	1.71	.32	.13	2.24	2.38	.75	.08
Tissue[g]									
Subcutaneous	4.02	2.09	27.3	6.12	1.07	10.2	43.2	3.48	.61
Perirenal	3.82	.77	27.8	3.00	1.19	24.8	34.1	2.95	.49
SD	.66	.29[j]	1.94	.70[j]	.16	1.94[j]	2.27[j]	.74[h]	.12[i]

[a]Because perirenal adipose tissue was obtained at slaughter, the composition of this tissue was compared with composition of subcutaneous adipose tissue obtained at slaughter.
[b]Values are weight percentages of all values observed.
[c]Treatments are described in the text and in footnote [a] of Table 2.
[d]Standard deviation.
[e,f]For treatment effect on perirenal adipose tissue, means with different superscripts differ ($P < .05$).
[g]Values computed by pooling data across treatments.
[h]Tissues differ ($P < .05$).
[i]Tissues differ ($P < .01$).
[j]Tissues differ ($P < .001$).

response to the high-fat diet. The proportion of total unsaturated fatty acids of subcutaneous adipose tissue tended to increase with the time that cattle were being fed the soybean-supplemented diet: (time 1 vs. slaughter) C=47.8 vs. 52.6 wt%; CS=47.1 vs. 53.2 wt%, and S=46.7 vs. 54.8 wt%.

Effects of dietary soybeans on fatty acid composition of subcutaneous adipose tissue were similar to those observed by both Dryden et al. (11) and Dryden and Marchello (23), who compared cattle fed diets containing 6% safflower oil with control cattle. The only diet-related differences observed by Dryden et al. (11) were with the proportion of 18:2 and 18:3 fatty acids, which were greatest in the safflower oil-fed cattle. Diet-induced differences in proportions of 18:2, however, were of greater magnitude (up to 80%) than were observed in the present study (up to 23%).

Perirenal adipose tissue. Perirenal adipose tissue obtained at slaughter from both CS and S steers had a greater ($P < .05$) proportion of 18:3 than did that of C steers (Table 3). Also, the proportion of 18:2 was 37% greater for CS and S steers than for C steers. Likewise, Roberts and McKirdy (24) found the proportion of unsaturated fatty acids to increase in perirenal adipose tissue of cattle fed diets that contained highly unsaturated rapeseed oil. Similar to results of Table 3, diets that contained 6% safflower oil (23) or 5% soybean oil (25) resulted in an increased proportion of 18:2 in perirenal adipose tissue of the cattle fed them.

Also shown in Table 3 is a comparison of fatty acid composition of perirenal with subcutaneous adipose tissue. Compared with perirenal adipose tissue, weight percentage of fatty acids of subcutaneous adipose tissue was greater for 15:0, 16:1, 18:1 and 18:3 and lesser for 18:0. Overall, subcutaneous adipose tissue had 53.4% by weight unsaturated acids, and perirenal adipose tissue had 40.5% unsaturated acids. These differences were similar in type and magnitude to those reported by Cabezas et al. (12), Waldman et al. (26), Booren et al. (27), Dryden and Marchello (23) and Garrett et al. (1). The lesser content of unsaturated fatty acids in perirenal adipose tissue has been attributed to the slightly greater average temperature of this adipose tissue depot compared with that of subcutaneous adipose tissue (25,28).

Blood plasma. Fatty acid composition of total lipids of blood plasma is shown in Table 4. Blood plasma obtained at time 1 contained proportions of 18:3 that were different ($P < .05$) for steers allotted to the three dietary treatments. Because all the steers had been fed the same control diet up to this point, the reason for this difference is not known.

At sampling time 2, S steers had proportions of 15:0 and 16:1 that were less ($P < .05$) than those of either C or CS steers. Also, S steers had lesser proportions of 14:0 and 17:0, but these differences were not significant. Proportion of 18:2 was greater for S steers than for C steers but not different from that of CS steers ($P > .05$) at time 2. Although not significantly greater, S steers had 23% more 18:3 than did either the C or CS steers at sampling time 2. At sampling time 3, proportions of 14:0, 15:0, 16:1 and 17:0 of CS steers changed to proportions that were similar to those of S steers; approximately three weeks before sampling time 3, CS steers had been switched from the control to the soybean-containing diet. Both S and CS steers had lesser ($P < .05$) proportions of 15:0 and greater ($P < .05$) proportions of 18:3 than did C steers. At time 4, differences in values between treatments for 14:0, 15:0, 16:1 and 17:0 were similar to those of time 3. For 18:2, the diet effect observed at time 2 was not observed at time 3. At time 4, however, CS and S steers had similar

TABLE 4

Fatty Acid Composition of Lipids of Blood Plasma of Steers Fed the Control or High-Fat Diets

	Fatty acid[a]								
Treatment[b,c]	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Sampling Time = 1[d]									
C	1.04	.68	13.9	2.45	1.08	22.1	10.9	38.6	1.65[f]
CS	1.25	.76	14.9	2.55	.98	22.0	10.8	38.0	1.20[g]
S	1.11	1.19	15.2	2.70	1.03	22.3	10.6	38.5	.98[h]
SD[e]	.34	.51	1.1	.45	.10	1.1	1.61	4.84	.04
Sampling Time = 2									
C	1.30	.52[f]	13.8	2.30[f]	1.20	21.9	9.96	40.5[g]	1.06
CS	1.20	.58[f]	13.4	2.30[f]	1.15	21.4	9.70	42.0[f,g]	1.05
S	.85	.35[g]	13.1	1.75[g]	.88	22.8	7.45	45.6[f]	1.30
SD	.23	.06	.71	.14	.10	.41	.86	1.30	.20
Sampling Time = 3									
C	1.10	.49[f]	13.9	2.20	1.06	20.4	9.27	43.2	.64[g]
CS	.83	.34[g]	14.6	1.80	.83	21.8	9.25	41.5	1.25[f]
S	.88	.33[g]	13.8	1.70	.86	23.2	8.10	44.2	1.15[f]
SD	.28	.03	1.03	.20	.20	1.48	.55	2.18	.13
Sampling Time = 4									
C	1.10	.43	14.0	2.24	1.00	21.9	9.40	41.8	.61[g]
CS	.81	.34	13.6	1.65	.81	23.4	8.25	43.3	1.00[f]
S	.85	.37	13.5	1.85	.83	22.5	9.05	43.0	1.20[f]
SD	.23	.06	.41	.23	.10	1.09	1.02	1.41	.10

[a]Values are weight percentages of all fatty acids observed.
[b]Treatments are described in text and in Footnote [a] of Table 2.
[c]For each treatment, n=2.
[d]Sampling times are described in footnote [c] of Table 2.
[e]Standard deviation.
[f,g,h]Means with different superscripts in columns within sampling times differ ($P < .05$).

proportions of 18:2, and both had a greater proportion of 18:2 than did C steers. At times 3 and 4, plasma lipids of S and CS steers had similar ($P > .05$) proportions of 18:3 that were greater ($P < .05$) than those of C steers.

Overall, the effect of dietary extruded soybeans on fatty acid composition of lipids from blood plasma was an increase in proportions of 18:2 and 18:3 and a concomitant decrease in proportions of 14:0, 15:0, 16:1 and 17:0. Others have shown similar responses to greater intakes of polyunsaturated fats by cattle (29-31).

Muscle lipids. Fatty acid compositions of lipids of *M. trapezius* at times 1 through 3 and of *M. longissimus* at time 4 are shown in Table 5. No significant differences were observed between diets within any sampling time. In contrast, Dryden and Marchello (23) found the lipids of *M. longissimus, M. triceps brachii* and *M. semimembranosus* of steers to have significantly greater proportions of 18:2 when their diets contained 6% safflower oil. Other than the study by Dryden and Marchello (23), no other data on effects of dietary unsaturated fat on composition of fatty acids of skeletal muscle lipids in cattle have been reported, except for data from studies on feeding cattle formaldehyde-treated lipids.

For steers slaughtered in November (fall), the range of weight percentages of 18:2 in *M. longissimus* was from 6.1 to 9.1% for S steers and from 5.9 to 8.8% for C steers. In contrast, steers slaughtered in January (winter) had *M. longissimus* weight percentages of 18:2 that ranged from 6.2 to 12.6% for S steers and from 7.2 to 8.0% for C steers. When lipid percentage of *M. longissimus* was regressed against proportion of 18:2 in this tissue, a negative correlation was observed for the November slaughter group ($r=-.74$, $P=.04$). For the January slaughter group, a smaller and nonsignificant negative correlation was observed ($r=-.29$, $P=.48$). These results suggest that addition of full-fat soybeans to high-energy diets during cold winter months may result in deposition of greater quantities of dietary 18:2 in skeletal muscle. Similar effects of temperature were observed by Link et al. (32) for intramuscular lipids of cattle and by Marchello et al. (28) for adipose tissue of sheep.

Effect of sampling time. Effects of length of time that cattle were fed diets on fatty acid composition of tissues and plasma lipids are in Table 6. For subcutaneous adipose tissue, proportions of 14:0, 16:0 and 18:0 decreased ($P < .05$) with time, and proportions of 16:1, 18:1, 18:2 and 18:3 in adipose tissue increased ($P < .05$). The decrease in proportion of 16:0 and 18:0 and concomitant increase in proportions of 16:1 and 18:1 probably were the result of increased desaturase activity, which was shown by Pothoven et al. (33) to increase with age in subcutaneous adipose tissue of steers. The increase in proportions of 18:2 and 18:3 suggests that rumen microbial hydrogenation of feed lipids decreases with age; however, this may have been the result of greater feed intakes, which would have decreased the relative amounts of unsaturated feed

TABLE 5

Fatty Acid Composition of Muscle Lipids of Steers Fed the Control or High-Fat Diets[a]

	Fatty acid[b]								
Treatment[c]	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Sampling Time = 1[d]									
C[e]	5.20	1.85	30.9	5.40	1.25	13.5	36.6	3.80	.34
CS	4.85	2.10	31.0	5.60	1.05	13.3	37.6	2.70	.36
S	4.95	2.40	30.6	5.65	1.35	12.8	38.1	2.55	.40
SD[f]	.33	.28	.44	.45	.14	1.12	.34	1.12	.03
Sampling Time = 2									
C	4.80	1.90	30.0	6.65	1.05	11.6	39.5	2.60	.38
CS	4.65	1.90	30.3	6.00	.96	12.6	39.2	2.60	.27
S	4.90	2.20	30.6	6.05	1.08	11.8	38.5	3.30	.40
SD	.27	.27	.41	.44	.10	1.00	.52	.74	.06
Sampling Time = 3									
C	4.65	2.35	29.7	6.60	1.10	10.5	40.6	2.45	.41
CS	5.15	2.30	30.4	6.20	.99	11.4	39.2	2.70	.52
S	5.10	2.30	31.0	6.15	.94	11.4	38.7	2.80	.44
SD	.42	.61	1.34	.55	.10	1.40	1.39	.66	.06
Sampling Time = 4									
C[g]	4.18	1.15	26.6	4.28	.95	12.8	37.7	7.66	.57
CS	4.17	1.14	26.9	4.12	.75	13.2	35.9	8.73	.64
S	4.27	1.23	27.2	4.15	.85	13.8	36.5	7.70	.79
SD	.49	.27	1.43	.52	.19	1.06	2.23	2.41	.26

[a]Muscle, *M. trapezius* for sampling times 1 through 3 and *M. longissimus* for sampling time 4.
[b]Values are weight percentages of all fatty acids observed.
[c]Treatments are described in footnote [a] of Table 2.
[d]Sampling times are described in footnote [c] of Table 2.
[e]n, 2 for C, CS and S at sampling times 1-3.
[f]Standard deviation.
[g]n, 5 for C; n,6 for CS and S at sampling time 4.

lipids saturated in the rumen. Overall, as time progressed and steers grew, an increase from 47.1 to 53.4% in total percentage of unsaturated fatty acids was observed in subcutaneous adipose tissue. Increases in proportions of unsaturated fatty acids in subcutaneous adipose tissue of cattle (11,25,34,35) and sheep (28,36) during growth have been reported previously. In contrast to the present study, Terrell et al. (37) found that only 10:0, 12:0 and 14:0 changed significantly in subcutaneous adipose tissue of cattle during growth. Waldman et al. (26) found that growth of cattle from 386 to 454 kg resulted in increased 18:1, while 18:2 and 18:3 decreased. In the present study, proportions of 16:1, 18:1 and 18:3 of lipids of *M. trapezius* increased ($P < .05$) from time 1 to time 3 and those of 17:0 and 18:0 decreased ($P < .05$). During growth in cattle, Hecker et al. (34) found the proportion of 16:1 to decrease and that of 18:2 to increase in lipids from *M. biceps femoris*; no changes were observed for proportions of 17:0, 18:0 and 18:1. Waldman et al. (26) and Link et al. (32) also found intramuscular lipids to increase in unsaturation during growth in cattle.

The proportion of unsaturated fatty acids of plasma lipids (Table 6) increased slightly from time 1 to time 4. Among the specific fatty acids, decreased proportions ($P < .05$) were observed for 15:0, 16:1, 17:0 and 18:1, whereas that of 18:2 increased ($P < .05$). Similar results were observed by Clemens et al. (31). In contrast, Hecker et al. (34) did not show these fatty acids to change in serum lipids of cattle during growth.

Duodenal ingesta. Fatty acid compositions of diets C and S, of diet S plus enough additional extruded soybeans for 9% dietary fat and of duodenal ingesta are shown in Table 7. The 9% fat diet was fed to determine if the extent of microbial hydrogenation of lipids of soybeans differs when fed at concentrations greater than 6% dietary fat. As expected, lipids of these three diets contained similar proportions of fatty acids. In general, analysis of lipids extracted from duodenal ingesta revealed only minor differences. Duodenal ingesta of steers fed the control diet had greater ($P < .05$) proportions of 14:0 and 15:0 fatty acids than did the steers fed the soybean-containing diets. Duodenal ingesta of steers fed the 6% fat diet had greater ($P < .05$) proportions of 14:0 and 16:0 than did that of steers fed the 9% fat diet. There were no differences ($P < .05$) in proportions of polyunsaturated fatty acids in lipids of duodenal ingesta. It seems, therefore, that the polyunsaturated fatty acids of high-fat diets are hydrogenated in proportions similar to those of conventional diets but not necessarily in similar amounts. With increasing fat in diets, total lipid consumption increased because daily consumption of each diet was similar, averaging 6.4 kg per day, and ether extracts of duodenal contents were 13.0 ± 1.60, 18.1 ± 1.10 and 20.9 ± 1.18% for diets C, S and S (9% fat), respectively.

Overall, the proportions of fatty acids of lipids of duodenal ingesta were not affected by dietary content of

TABLE 6

Effect of Sampling Time on Fatty Acid Composition of Lipids of Subcutaneous Adipose Tissue, Muscle and Plasma[a]

	Fatty acid[b]								
Sampling times[c]	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Subcutaneous Adipose Tissue									
1	4.56^{g}	1.95	29.4^{g}	5.27^{h}	1.33	14.3^{g}	38.9^{i}	2.51^{h}	.44^{h}
2	4.54^{g}	1.93	28.8^{g,h}	5.49^{g,h}	1.29	13.0^{h}	40.5^{h,i}	2.68^{h}	.47^{h}
3	4.19^{h}	1.98	28.2^{g,h}	5.78^{g,h}	1.17	11.9^{i}	41.9^{g,h}	3.16^{g}	.56^{g}
4	4.02^{i}	2.09	27.3^{g}	6.12^{g}	1.07	10.2^{j}	43.2 ^{g}	3.48^{g}	.61^{g}
SD[d]	.29	.16	.78	.62	.95	.95	1.44	.33	.08
Muscle[e]									
1	5.00	2.12	30.8	5.55^{g}	1.22^{g}	13.2^{g}	37.4^{g}	3.02	.36^{h}
2	4.78	2.00	30.3	6.23^{h}	1.03^{h}	12.0^{g,h}	39.0^{h}	2.83	.35^{h}
3	4.97	2.32	30.3	6.32^{h}	1.01^{h}	11.1^{h}	39.5^{h}	2.65	.45^{g}
SD	.58	.62	1.32	.74	.21	1.77	1.77	1.40	.11
Plasma[f]									
1	1.13	.88^{g}	14.7	2.57^{g}	1.03^{g,h}	22.1	10.7^{g}	38.6^{h}	1.28
2	1.12	.48^{h}	13.4	2.12^{h}	1.08^{g}	22.0	9.04^{h}	42.7^{g}	1.13
3	.94	.39^{h}	14.1	1.90^{h}	.92^{g,h}	21.8	8.87^{h}	43.0^{g}	1.01
4	.92	.38^{h}	13.7	1.92^{h}	.88^{h}	22.6	8.90^{h}	42.7^{g}	.94
SD	.41	.41	1.36	.49	.21	1.81	1.77	4.32	.49

[a]Because relative changes in fatty acids over time were similar among treatments, data for each fatty acid was pooled across treatments. For adipose tissue, the effect of sampling time was tested using the mean square for the treatment × block × sampling time interaction as the error term. For muscle and plasma, sampling times served as blocks and were tested using the mean square for the treatment × block interaction as the error term.

[b]Values are weight percentages of all fatty acids observed.

[c]Sampling times are described in footnote [c] of Table 2.

[d]Standard deviation.

[e]*M. trapezius.*

[f]Values for 14:0 and 18:3 were influenced somewhat by diet but sampling times did not differ ($P > .05$).

[g,h,i,j]Means with different superscripts in columns within tissues differ ($P < .05$).

TABLE 7

Fatty Acid Composition of Experimental Diet Lipids and Duodenal Ingesta of Holstein Steers Fed the Experimental Diets

	Fatty acid[a]								
Item	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3
Diet[b]									
C	.12	.03	12.5	.45	.18	2.70	19.9	55.1	5.74
S, 6% fat	.12	.03	12.9	.37	.18	3.29	21.7	54.5	6.17
S, 9% fat	.11	.03	11.8	.23	.15	3.80	23.7	53.2	6.49
Duodenal ingesta[c]									
C	.86^{e}	.46^{e}	12.8^{e,f}	.85	.86	56.7	19.1	5.31	.97
S, 6% fat	.51^{f}	.23^{f}	13.1^{e}	.51	.48	58.8	17.7	5.52	.78
S, 9% fat	.25^{g}	.12^{f}	12.2^{f}	.49	.62	52.6	24.1	6.16	.60
SD[d]	.05	.07	.23	.17	.33	2.26	2.32	.83	.10

[a]Values are weight percentage of all fatty acids observed.

[b]Diets: C, control; S, 6% = soybeans added to provide 6% dietary fat; S, 9% = soybeans added to provide 9% dietary fat.

[c]Duodenal ingesta of steers fed the respective diets.

[d]Standard deviation.

[e,f]Means with different superscripts in columns differ ($P < .05$).

fat from soybeans. However, the greater amounts of ether extract in duodenal ingesta of steers fed soybean-containing diets indicate that more polyunsaturated fatty acids were available for absorption by the small intestine. This indication is supported by the greater proportions of 18:3 that were observed in plasma lipids of S and CS steers than in those of C steers at sampling times 3 and 4. Although the major portion of polyunsaturated fatty acids of blood lipids normally occurs as phospholipid and cholesteryl esters (29), more polyunsaturated fatty acids would have been transported as triglycerides in plasma of soybean-fed steers

because of the greater proportions of these fatty acids in adipose tissue that occurred in response to dietary soybeans.

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