

## EFFECTS OF DIETARY REGIMEN AND TISSUE SITE ON BOVINE FATTY ACID PROFILES

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### Summary

A study is presented of the variation in fatty acid composition of bovine tissue as a function of dietary regimen—*forage vs grain*—and of tissue location within the carcass. Detailed fatty acid profiles were obtained by procedures that included dry column lipid extraction with concomitant isolation of separate neutral and polar fractions, capillary column gas chromatography, and computer assisted data storage, consolidation and statistical analysis. Separate fatty acid profiles for neutral lipid and polar lipid fractions were obtained both as normalized reports (each fatty acid as percentage of total fatty acid), and as "gravimetric" reports (mg each fatty acid/100 g tissue). In each set, side-by-side profiles allowed comparisons and statistically valid ( $P < .05$ ) conclusions to be made tissue-by-tissue within a dietary regimen and diet-by-diet for specific tissues. The fatty acids were grouped into several classes of unsaturation and branching for ease of comparison. Separate analysis of polar fractions allowed detailed examination of the polyunsaturates and gave profiles representative of muscle cells separate from contiguous intramuscular adipose cells. Numerous variations in specific fatty acid content are discussed. Reversals of some patterns occurred when comparisons were made gravimetrically rather than in a normalized manner. For example, normalized reports showed that tissues of *forage-fed* beef had higher percentages of normal and branched saturated fatty acids than did their *grain-fed*

counterparts. However, because tissue of *grain-fed* beef is fattier than that of *forage-fed* beef, this pattern was reversed in the gravimetric reports. Among the polyunsaturates, tissues of *grain-fed* beef provided greater quantities of the essential fatty acids (including linoleate) than did the *forage-fed* counterparts, as seen in the gravimetric reports, whereas the fatty acids of tissue of *forage-fed* beef had greater percentages of oxidation-prone nondienoic polyenes (including linolenate) than did the fatty acids of tissue of *grain-fed* beef, as seen in the normalized reports. Tissue-by-tissue comparisons showed that *psaos* major muscle and kidney knob adipose generally had the highest amounts of saturated fatty acids (normalized and gravimetric data) and essential fatty acids (gravimetric data), though the fatty acids of *semitendinosus* muscle had the highest concentration of nondienoic polyenes (normalized data).

(Key Words: Bovine, Fatty Acid, Diet, Muscle, Adipose, Rancidity.)

### Introduction

*Forage-fed* (F) beef has been considered to be less acceptable than *grain-fed* (G) beef primarily because of less desirable flavors (Reagan et al., 1977). Although some investigators have attributed lesser palatability to lower fat content (Moody, 1976; Harrison et al., 1978), others have looked at the composition of the fat and have related lesser palatability to overall unsaturation (Roberts, 1966; Rumsey et al., 1972; Brown et al., 1979) and to fatty acid composition (Brown et al., 1979; Westerling and Hedrick, 1979), or to the presence or absence of specific fatty acids (Melton et al., 1982). Implicated fatty acids, such as the readily oxidized polyunsaturate linolenic acid (18:3 $\omega$ 3c), are responsible for development of species flavor of meat as a result of the formation of volatile compounds such as unsaturated aldehydes, volatile fatty acids, methyl ketones,

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and saturated aldehydes produced from long chain fatty acids during cooking (Dwivedi, 1975).

Because of the implications that individual fatty acids may contribute to undesirable flavors, we undertook a study of fatty acid profiles from tissue of forage- and grain-finished beef. This study differs from prior investigations in the following manner. First, we examined specific tissues rather than composite samples to allow tissue-to-tissue comparisons. Secondly, tissue lipids were examined as neutral and polar fractions rather than as total lipid isolates; this allowed more precise examination of the polyunsaturated fatty acids, which are concentrated in the polar lipid fraction, and also allowed an estimate of the contribution of infiltrated adipose tissue, which affected mainly the neutral lipid fraction of the muscle. Finally, results are presented in two formats. Fatty acid content by mg/100 g tissue ("gravimetric" reports) provides absolute amounts per tissue portion, consistent with most food composition tables; normalized reports (g/100 g fatty acid) eliminate the bias in the gravimetric reports caused by the fattiness of the tissue.

#### Materials and Methods

Yearling Brangus × Hereford × Angus steers (348 kg) were finished (10/treatment) either on

a high grain diet (79% corn, 129 d) or a forage program (primarily winter wheat, 202 d) prior to slaughter. Detailed information on animals and dietary regimens is given by Williams et al. (1983), and corresponds to the "second year" study. Approximately 200-g samples of five selected tissues were separated from each carcass (10 animals/dietary regimen), sealed with minimum air into plastic bags, and shipped over dry ice from Oklahoma State University to the Eastern Regional Research Center. The five tissues included three muscle samples—longissimus (LM; ribeye excised from between the 12th and 13th rib), semitendinosus (ST; eye of round), and psoas major (PM; tenderloin)—and two adipose samples—subcutaneous (SQ; backfat attached to LM samples, but including fat from between the 11th and 12th ribs if insufficient sample was attached to the LM sample), and perinephric (KD; kidney knob fat). Upon receipt, the samples were stored at -60 C until they were comminuted and extracted for their lipid by the dry column method of Marmer and Maxwell (1981). This extraction allowed for concomitant separation of the lipid into separate neutral and polar fractions. Information on lipid content for the examined tissues and lipid fractions is given in table 1. Percentages of lipid in the neutral and polar fractions are means and standard errors of 10 animals for each tissue type (nine for LD). Percentage phos-

TABLE 1. LIPID CONTENT OF EXAMINED TISSUES

Tissue <sup>a</sup>	Neutral lipid <sup>b</sup>	Polar lipid	Total lipid	Phospho-lipid <sup>c</sup>	Polar factor <sup>d</sup>
	%				
Muscle					
ST <sub>F</sub>	2.17 ± 1.52	.91 ± .15	3.08 ± 1.60	.67 ± .03	.2798
ST <sub>G</sub>	3.82 ± 1.19	.94 ± .13	4.76 ± 1.13	.64 ± .06	.1441
PM <sub>G</sub>	5.25 ± 2.26	.99 ± .14	6.24 ± 2.34	.79 ± .04	.1261
LM <sub>G</sub>	5.23 ± 1.73	.75 ± .19	5.98 ± 1.64	.59 ± .07	.08957
Adipose					
SQ <sub>F</sub>	80.03 ± 8.85	1.51 ± .77	81.54 ± 9.19	.11 ± .04	.04197
SQ <sub>G</sub>	85.94 ± 1.87	.82 ± .44	86.76 ± 1.84	.07 ± .03	.008796
KD <sub>G</sub>	93.55 ± 1.04	.78 ± .68	94.33 ± .85	.02 ± .01	.01110

<sup>a</sup>Abbreviations: F: forage-fed; G: grain-fed; ST: semitendinosus; PM: psoas major; LM: longissimus muscle; SQ: subcutaneous; KD: kidney knob.

<sup>b</sup>Weight percentage of wet tissue.

<sup>c</sup>25.0 × percentage phosphorus.

<sup>d</sup>(mg fatty acid in polar fraction/100 g tissue)/(mg fatty acid in combined neutral and polar fractions/100 g tissue); used to apportion normalized data (tables 2 to 5) if construction of table of normalized data of total lipid is desired.

phospholipid figures are similarly calculated means based on phosphorus analysis of polar lipid fractions. A factor of 25.0 was used to convert percentage P to percentage phospholipid (Maxwell and Marmer, 1983). This tabulation includes a "polar factor" for each tissue. This factor, indicative of the amount of (derivatized) fatty acid found in the polar fraction relative to fatty acid in both neutral and polar fractions, equals the total mg fatty acid in the polar lipid fraction/100 g tissue divided by the total mg fatty acid in both polar and neutral lipid fractions/100 g tissue. It enables the construction of a normalized fatty acid profile of total lipid by apportioning the normalized values in tables 1 and 2. Such a total profile would not include statistical conclusions.

Lipid was derivatized and the resulting mixtures of fatty acid methyl esters (FAME) were analyzed by capillary column gas chromatography (Maxwell and Marmer, 1983). The "normalized" data (weight percent of total FAME) from 280 individual gas chromatography (GC) runs were consolidated (Marmer et al., 1983) and subjected to an analysis of variance and Bonferroni mean separation techniques (Miller, 1981) to discern statistically significant differences in profiles as a function of dietary regimen (tables 2 and 3) and tissue site (tables 4 and 5). In addition to the normalized reports, use of an internal standard during GC analysis allowed data to be tabulated and statistically analyzed in gravimetric units deemed most appropriate by Kinsella et al. (1975; mg fatty acid/100 g tissue; tables 2 to 5). Although common fatty acids were seen in each animal of a set (typically 10 forage or grain animals), for those fatty acids encountered in less than the full set, statistical comparisons were deemed valid if at least three degrees of freedom were guaranteed (five for three-way comparisons). Tables 2 through 5 each contain statistical comparisons within four separately studied groups. Therefore, four sets of superscript symbols were used to denote significant differences (all  $P < .05$ ): (1) for tables 2 and 3: a, b for mg data and c, d for normalized data,  $ST_F$  vs  $ST_G$ ; similarly, e, f and g, h for  $SQ_F$  vs  $SQ_G$ ; (2) for tables 3 and 4: a, b, c for mg data and d, e, f for normalized data,  $ST_G$  vs  $PM_G$  vs  $LM_G$ ; similarly, g, h and i, j for  $SQ_G$  vs  $KD_G$ . Each line in the tables provides comparisons independent of the comparisons of other lines. Entries without superscripts were not compared due to insufficient data. For

brevity, data for individual, unidentified peaks are not shown in tables 2 to 5, though the sums are given for unidentified saturated fatty acids and for unidentified unsaturated fatty acids. All these peaks were extremely small, often not seen, and in their sums usually under 5% of the peak area for any GC run.

It should be noted that the normalized data are not simply a normalization of the parallel gravimetric data, but instead are generated independently and directly from the GC reports. Because of editing procedures during data consolidation (Marmer et al., 1983) and because polar lipid fractions contained variable amounts of non-fatty-acid bearing lipid, the parallel normalized and gravimetric data occasionally may not appear consistent.

### Results and Discussion

The data in table 1 demonstrate that tissue from forage-fed beef is leaner than tissue from grain-fed beef. For ST tissue, this was observed in the neutral lipid fraction, and resulted from infiltrated adipose tissue. The similar pattern for SQ tissue probably resulted from increased amounts of connective tissue in the forage-fed sample. The polar adipose fractions had little phospholipid and considerable carryover of neutral lipid; nevertheless, the utility of isolating separate polar fractions may be verified by the detection of minute amounts of polyunsaturated fatty acids only in the polar fractions (tables 3 and 5, but not tables 2 and 4).

Derivatization of the lipid fractions, analysis, and data consolidation resulted in the fatty acid profiles shown in tables 2 through 5. The tables have been assembled into two sections: tables 2 and 3 compare profiles from tissues of forage-fed vs grain-fed beef, whereas tables 4 and 5 compare profiles of five tissues from grain-fed beef. Within each section, profiles are presented of neutral lipid fractions (tables 2 and 4) and of polar lipid fractions (tables 3 and 5). Each table displays the profiles in two formats, gravimetric (mg/100 g tissue) and normalized (% of total fatty acid). The individual fatty acids in the tables are grouped as normal saturated, branched saturated, trans monoene, cis monoene, diene, and nondienoic polyene, and these groupings form the basis for the following discussion of the data. Sets of data that show statistical differences are highlighted in the tables.

*Fatty Acid Profiles, Forage vs Grain. Com-*

TABLE 2. FATTY ACID COMPOSITION<sup>a</sup> OF NEUTRAL LIPID FRACTIONS AS A FUNCTION OF DIETARY REGIMEN

Fatty acid	Muscle (ST)				Adipose (SQ)			
	mg/100 g tissue		Normalized (%)		mg/100 g tissue		Normalized (%)	
	F	G	F	G	F	G	F	G
<b>Saturated</b>								
Normal								
14:0	45 <sup>b</sup>	109 <sup>a</sup>	3.20 <sup>c</sup>	3.17 <sup>c</sup>	2,862 <sup>e</sup>	2,738 <sup>e</sup>	3.92 <sup>g</sup>	3.28 <sup>h</sup>
15:0	8 <sup>b</sup>	22 <sup>a</sup>	.57 <sup>c</sup>	.65 <sup>c</sup>	475 <sup>f</sup>	582 <sup>e</sup>	.66 <sup>g</sup>	.70 <sup>g</sup>
16:0	393 <sup>b</sup>	900 <sup>a</sup>	27.54 <sup>c</sup>	26.55 <sup>c</sup>	19,630 <sup>e</sup>	21,683 <sup>e</sup>	27.07 <sup>g</sup>	25.99 <sup>h</sup>
17:0	16 <sup>b</sup>	57 <sup>a</sup>	1.12 <sup>d</sup>	1.68 <sup>c</sup>	795 <sup>f</sup>	1,659 <sup>e</sup>	1.09 <sup>h</sup>	1.99 <sup>g</sup>
18:0	207 <sup>b</sup>	360 <sup>a</sup>	14.41 <sup>c</sup>	10.63 <sup>d</sup>	11,353 <sup>e</sup>	10,475 <sup>e</sup>	15.60 <sup>g</sup>	12.50 <sup>h</sup>
20:0		219		.16		219		.24
Sum	670	1,667	46.84	42.84	35,114	37,357	48.34	44.70
Branched								
i15:0	4 <sup>a</sup>	4 <sup>a</sup>	.27 <sup>c</sup>	.11 <sup>d</sup>	280 <sup>e</sup>	98 <sup>f</sup>	.39 <sup>g</sup>	.12 <sup>h</sup>
ai15:0	4 <sup>a</sup>	4 <sup>a</sup>	.28 <sup>c</sup>	.12 <sup>d</sup>	292 <sup>e</sup>	105 <sup>f</sup>	.40 <sup>g</sup>	.13 <sup>h</sup>
i16:0	3 <sup>a</sup>	14 <sup>a</sup>	.23 <sup>c</sup>	.11 <sup>d</sup>	206 <sup>e</sup>	97 <sup>f</sup>	.29 <sup>g</sup>	.11 <sup>h</sup>
ai17:0	10 <sup>a</sup>	14 <sup>a</sup>	.72 <sup>c</sup>	.42 <sup>d</sup>	586 <sup>e</sup>	393 <sup>f</sup>	.81 <sup>g</sup>	.47 <sup>h</sup>
ai19:0	3 <sup>a</sup>	17 <sup>a</sup>	.24 <sup>d</sup>	.53 <sup>c</sup>	136 <sup>f</sup>	363 <sup>e</sup>	.19 <sup>h</sup>	.44 <sup>g</sup>
Sum	25	43	1.74	1.28	1,500	1,056	2.07	1.27
Unidentified sum	23	22	1.52	.69	1,224	466	1.68	.55
Total saturated	717	1,733	50.10	44.81	37,838	38,879	52.09	46.52
<b>Unsaturated</b>								
trans-Monoene								
16:1 $\omega$ 7t	1		.14		72		.13	
18:1t	40 <sup>a</sup>	70 <sup>a</sup>	2.78 <sup>c</sup>	2.04 <sup>d</sup>	2,845 <sup>e</sup>	2,279 <sup>f</sup>	3.93 <sup>g</sup>	2.71 <sup>h</sup>
Sum	41	70	2.92	2.04	2,917	2,279	4.06	2.71
cis-Monoene								
14:1 $\omega$ 5c	10 <sup>b</sup>	27 <sup>a</sup>	.76 <sup>c</sup>	.84 <sup>c</sup>	778 <sup>e</sup>	718 <sup>e</sup>	1.07 <sup>g</sup>	.86 <sup>g</sup>
16:1 $\omega$ 7c	46 <sup>b</sup>	133 <sup>a</sup>	3.31 <sup>d</sup>	4.01 <sup>c</sup>	2,661 <sup>e</sup>	2,750 <sup>e</sup>	3.70 <sup>g</sup>	3.30 <sup>h</sup>
17:1 $\omega$ 8c	10 <sup>b</sup>	54 <sup>a</sup>	.76 <sup>d</sup>	1.65 <sup>c</sup>	490 <sup>f</sup>	1,210 <sup>e</sup>	.69 <sup>h</sup>	1.46 <sup>g</sup>
18:1 $\omega$ 9c	513 <sup>b</sup>	1,375 <sup>a</sup>	36.52 <sup>d</sup>	41.55 <sup>c</sup>	24,032 <sup>f</sup>	33,538 <sup>e</sup>	33.32 <sup>h</sup>	40.15 <sup>g</sup>
18:1 $\omega$ 7c	19 <sup>b</sup>	60 <sup>a</sup>	1.38 <sup>d</sup>	1.83 <sup>c</sup>	819 <sup>f</sup>	1,354 <sup>e</sup>	1.14 <sup>h</sup>	1.62 <sup>g</sup>
20:1 $\omega$ 9c	3	4	.12	.16	162	155	.19	.18
Sum	602	1,654	42.86	50.04	28,943	39,726	40.10	47.58
Diene								
18:2 $\omega$ 6c	16 <sup>b</sup>	55 <sup>a</sup>	1.16 <sup>d</sup>	1.62 <sup>c</sup>	420 <sup>f</sup>	1,498 <sup>e</sup>	.60 <sup>h</sup>	1.79 <sup>g</sup>
20:2 $\omega$ 6c								
Sum	16	55	1.16	1.62	420	1,498	.60	1.79

Nondienoic polyene								
18:3 $\omega$ 3c	8 <sup>a</sup>	6 <sup>a</sup>	.58 <sup>c</sup>	.19 <sup>d</sup>	340 <sup>e</sup>	118 <sup>f</sup>	.47 <sup>g</sup>	.14 <sup>h</sup>
20:3 $\omega$ 6c	<1		.10		83		.16	
20:4 $\omega$ 6c	2 <sup>a</sup>	6 <sup>a</sup>	.30 <sup>c</sup>	.16 <sup>c</sup>				
20:5 $\omega$ 3c	<1		.11		83		.16	
22:4 $\omega$ 6c								
22:5 $\omega$ 3c								
22:6 $\omega$ 3c								
Sum	11	12	1.09	.35	506	118	.79	.14
Unidentified sum	27	35	1.88	1.14	1,743	1,072	2.36	1.27
Total monoene	642	1,724	45.78	52.08	31,860	42,005	44.16	50.29
Total $\omega$ 6 polyene	18	60	1.56	1.78	504	1,498	.76	1.79
Total $\omega$ 3 polyene	8	6	.69	.19	423	118	.63	.14
Total unsaturated	696	1,825	49.91	55.19	34,530	44,693	47.91	53.49
Total	1,414	3,558	100.01	100.00	72,368	83,571	100.00	100.01

<sup>a</sup>Bonferroni t-tests were used to make specific comparisons between fatty acids as a function of dietary regimen. The following four comparisons and associated separation symbols are used above: <sup>a</sup>,<sup>b</sup>ST<sub>F</sub> vs ST<sub>G</sub>, mg/100 g tissue; <sup>c</sup>,<sup>d</sup>ST<sub>F</sub> vs ST<sub>G</sub>, normalized; <sup>e</sup>,<sup>f</sup>SQ<sub>F</sub> vs SQ<sub>G</sub>, mg/100 g tissue; <sup>g</sup>,<sup>h</sup>SQ<sub>F</sub> vs SQ<sub>G</sub>, normalized. For a given row, values with no superscripts were not compared due to insufficient data. Abbreviations: cf. footnote a, table 1. Fatty acid structures are indicated by [chain length:number of methylene-interrupted double bonds];  $\omega$ 3: double bond system progresses toward the carboxylate functionality from the third carbon from the hydrophobic end ( $\omega$ 3 carbon). i: iso (CH<sub>3</sub> on  $\omega$ 2 carbon); ai: anteiso (CH<sub>3</sub> on  $\omega$ 3 carbon).

TABLE 3. FATTY ACID COMPOSITION<sup>a</sup> OF POLAR LIPID FRACTIONS AS A FUNCTION OF DIETARY REGIMEN

Fatty acid	Muscle (ST)				Adipose (SQ)			
	mg/100 g tissue		Normalized (%)		mg/100 g tissue		Normalized (%)	
	F	G	F	G	F	G	F	G
Saturated								
Normal								
14:0	4 <sup>a</sup>	2 <sup>a</sup>	.68 <sup>c</sup>	.60 <sup>c</sup>	123 <sup>e</sup>	20 <sup>f</sup>	3.73 <sup>g</sup>	2.53 <sup>h</sup>
15:0	2 <sup>a</sup>	1 <sup>a</sup>	.58 <sup>c</sup>	.24 <sup>c</sup>	20 <sup>e</sup>	5 <sup>f</sup>	.63 <sup>g</sup>	.62 <sup>g</sup>
16:0	105 <sup>a</sup>	96 <sup>a</sup>	19.64 <sup>c</sup>	18.87 <sup>c</sup>	844 <sup>e</sup>	171 <sup>f</sup>	26.52 <sup>g</sup>	23.10 <sup>h</sup>
17:0	4 <sup>a</sup>	4 <sup>a</sup>	.84 <sup>c</sup>	.73 <sup>c</sup>	34 <sup>e</sup>	16 <sup>e</sup>	1.06 <sup>h</sup>	1.78 <sup>g</sup>
18:0	71 <sup>a</sup>	63 <sup>a</sup>	13.34 <sup>c</sup>	11.80 <sup>c</sup>	508 <sup>e</sup>	90 <sup>f</sup>	15.33 <sup>g</sup>	12.36 <sup>h</sup>
20:0	1 <sup>b</sup>	1 <sup>a</sup>	.17 <sup>c</sup>	.23 <sup>c</sup>	5 <sup>e</sup>	3 <sup>e</sup>	.20 <sup>g</sup>	.13 <sup>g</sup>
Sum	185	168	35.26	32.48	1,535	305	47.47	40.53

Branched								
i15:0	1	<1	.16	.23	12 <sup>e</sup>	1 <sup>e</sup>	.37 <sup>g</sup>	.14 <sup>h</sup>
ai16:0	1	<1	.14	.20	11 <sup>e</sup>	1 <sup>f</sup>	.36 <sup>g</sup>	.12 <sup>h</sup>
i16:0	1	<1	.13 <sup>c</sup>	.15 <sup>c</sup>	9 <sup>e</sup>	1 <sup>e</sup>	.27 <sup>g</sup>	.11 <sup>h</sup>
ai17:0	2	1	.26 <sup>c</sup>	.18 <sup>c</sup>	27 <sup>e</sup>	3 <sup>f</sup>	.81 <sup>g</sup>	.36 <sup>h</sup>
ai19:0	1	1	.11 <sup>c</sup>	.19 <sup>c</sup>	6 <sup>e</sup>	4 <sup>e</sup>	.20 <sup>h</sup>	.46 <sup>g</sup>
Sum	5	2	.80	.96	64	9	2.02	1.19
Unidentified sum	3	6	.50	1.03	31	9.	1.39	2.25
Total saturated	193	176	36.56	34.47	1,630	323	50.88	43.97
Unsaturated								
trans-Monoene								
16:1 $\omega$ 7t	4 <sup>a</sup>	1 <sup>b</sup>	.76 <sup>c</sup>	.17 <sup>d</sup>	1		.12	
18:1t	6 <sup>a</sup>	6 <sup>a</sup>	1.12 <sup>c</sup>	1.06 <sup>c</sup>	114 <sup>e</sup>	24 <sup>f</sup>	3.51 <sup>g</sup>	2.56 <sup>h</sup>
Sum	10	7	1.88	1.23	115	24	3.63	2.56
cis-Monoene								
14:1 $\omega$ 5c	1 <sup>a</sup>	1 <sup>a</sup>	.25 <sup>c</sup>	.26 <sup>c</sup>	32 <sup>e</sup>	5 <sup>f</sup>	1.03 <sup>g</sup>	.65 <sup>h</sup>
16:1 $\omega$ 7c	7 <sup>a</sup>	6 <sup>a</sup>	1.33 <sup>c</sup>	1.25 <sup>c</sup>	118 <sup>e</sup>	23 <sup>f</sup>	3.75 <sup>g</sup>	3.00 <sup>h</sup>
17:1 $\omega$ 8c	3 <sup>a</sup>	4 <sup>a</sup>	.59 <sup>d</sup>	.80 <sup>c</sup>	26 <sup>e</sup>	13 <sup>e</sup>	.81 <sup>h</sup>	1.45 <sup>g</sup>
18:1 $\omega$ 9c	119 <sup>a</sup>	97 <sup>a</sup>	22.08 <sup>c</sup>	19.08 <sup>c</sup>	1,028 <sup>e</sup>	267 <sup>f</sup>	32.42 <sup>g</sup>	34.52 <sup>g</sup>
18:1 $\omega$ 7c	10 <sup>a</sup>	13 <sup>a</sup>	1.88 <sup>d</sup>	2.38 <sup>c</sup>	48 <sup>e</sup>	14 <sup>f</sup>	1.37 <sup>h</sup>	1.77 <sup>g</sup>
20:1 $\omega$ 9c		4		.66	1 <sup>e</sup>	1 <sup>e</sup>	.12	.14
Sum	141	125	26.12	24.42	1,253	322	39.50	41.53
Diene								
18:2 $\omega$ 6c	70 <sup>b</sup>	110 <sup>a</sup>	12.45 <sup>d</sup>	18.63 <sup>c</sup>	27 <sup>e</sup>	20 <sup>e</sup>	.89 <sup>h</sup>	3.19 <sup>g</sup>
20:2 $\omega$ 6c	1	2	.09	.24		1		.15
Sum	71	112	12.54	18.87	27	21	.89	3.34
Nondienoic polyene								
18:3 $\omega$ 3c	16 <sup>a</sup>	5 <sup>b</sup>	2.74 <sup>c</sup>	.74 <sup>d</sup>	28 <sup>e</sup>	3 <sup>f</sup>	.72 <sup>g</sup>	.29 <sup>h</sup>
20:3 $\omega$ 6c	10 <sup>a</sup>	13 <sup>a</sup>	1.73 <sup>c</sup>	2.12 <sup>c</sup>	6 <sup>e</sup>	4 <sup>e</sup>	.20 <sup>g</sup>	1.09 <sup>g</sup>
20:4 $\omega$ 6c	37 <sup>a</sup>	52 <sup>a</sup>	6.03 <sup>c</sup>	8.08 <sup>c</sup>	10 <sup>e</sup>	7 <sup>e</sup>	.34 <sup>g</sup>	2.32 <sup>g</sup>
20:5 $\omega$ 3c	13 <sup>a</sup>	11 <sup>a</sup>	2.24 <sup>c</sup>	1.71 <sup>c</sup>	5	<1	.15	.27
22:4 $\omega$ 6c	3 <sup>b</sup>	6 <sup>a</sup>	.46 <sup>d</sup>	.87 <sup>c</sup>		1		.44
22:5 $\omega$ 3c	23 <sup>a</sup>	22 <sup>a</sup>	3.81 <sup>c</sup>	3.32 <sup>c</sup>	6 <sup>e</sup>	3 <sup>e</sup>	.20 <sup>g</sup>	1.08 <sup>g</sup>
22:6 $\omega$ 3c	2 <sup>a</sup>	3 <sup>a</sup>	.32 <sup>c</sup>	.43 <sup>c</sup>		1		.27
Sum	103	111	17.32	17.27	56	19	1.61	5.75
Unidentified sum	34	16	5.57	3.75	84	30	3.50	2.84
Total monoene	151	132	28.00	25.65	1,367	346	43.13	44.09
Total $\omega$ 6 polyene	120	183	20.76	29.94	43	33	1.43	7.19
Total $\omega$ 3 polyene	53	40	9.11	6.20	39	7	1.07	1.90
Total unsaturated	359	371	63.44	65.54	1,536	416	49.13	56.02
Total	552	547	100.00	100.01	3,166	740	100.01	99.99

TABLE 4. FATTY ACID COMPOSITION<sup>a</sup> OF NEUTRAL LIPID FRACTIONS AS A FUNCTION OF TISSUE SITE

Fatty acid	Muscle						Adipose				
	mg/100 g tissue			Normalized (%)			mg/100 g tissue		Normalized (%)		
	ST	PM	LM	ST	PM	LM	SQ	KD	SQ	KD	
<b>Saturated</b>											
<b>Normal</b>											
14:0	109 <sup>c</sup>	158 <sup>a</sup>	144 <sup>b</sup>	3.17 <sup>f</sup>	3.35 <sup>d</sup>	3.21 <sup>e</sup>	2,738 <sup>h</sup>	3,265 <sup>g</sup>	3.28 <sup>j</sup>	3.68 <sup>i</sup>	
15:0	22 <sup>c</sup>	31 <sup>a</sup>	29 <sup>b</sup>	.65 <sup>d</sup>	.66 <sup>d</sup>	.62 <sup>e</sup>	582 <sup>g</sup>	563 <sup>h</sup>	.70 <sup>i</sup>	.64 <sup>j</sup>	
16:0	900 <sup>c</sup>	1,270 <sup>a</sup>	1,157 <sup>b</sup>	26.55 <sup>d</sup>	26.91 <sup>d</sup>	26.41 <sup>d</sup>	21,683 <sup>g</sup>	23,359 <sup>h</sup>	25.99 <sup>i</sup>	26.66 <sup>i</sup>	
17:0	57 <sup>b</sup>	88 <sup>a</sup>	84 <sup>a</sup>	1.68 <sup>e</sup>	1.82 <sup>d</sup>	1.81 <sup>d</sup>	1,659 <sup>h</sup>	1,844 <sup>g</sup>	1.99 <sup>j</sup>	2.09 <sup>i</sup>	
18:0	360 <sup>c</sup>	681 <sup>a</sup>	566 <sup>b</sup>	10.63 <sup>f</sup>	14.42 <sup>d</sup>	12.72 <sup>e</sup>	10,475 <sup>h</sup>	22,018 <sup>g</sup>	12.50 <sup>j</sup>	24.71 <sup>i</sup>	
20:0	219		2	.16		.22	219	144	.24	.17	
Sum	1,667	2,229	1,981	42.84	47.16	44.98	37,357	51,193	44.70	57.55	
<b>Branched</b>											
i15:0	4 <sup>b</sup>	6 <sup>a</sup>	4 <sup>b</sup>	.11 <sup>e</sup>	.14 <sup>d</sup>	.10 <sup>e</sup>	98 <sup>h</sup>	152 <sup>g</sup>	.12 <sup>j</sup>	.17 <sup>i</sup>	
ai15:0	4 <sup>b</sup>	8 <sup>a</sup>	4 <sup>b</sup>	.12 <sup>e</sup>	.17 <sup>d</sup>	.10 <sup>f</sup>	105 <sup>h</sup>	200 <sup>g</sup>	.13 <sup>j</sup>	.23 <sup>i</sup>	
i16:0	4 <sup>c</sup>	7 <sup>b</sup>	13 <sup>a</sup>	.11 <sup>f</sup>	.15 <sup>e</sup>	.37 <sup>d</sup>	97 <sup>h</sup>	149 <sup>g</sup>	.11 <sup>j</sup>	.16 <sup>i</sup>	
ai17:0	14 <sup>c</sup>	25 <sup>a</sup>	17 <sup>b</sup>	.42 <sup>e</sup>	.52 <sup>d</sup>	.38 <sup>e</sup>	393 <sup>h</sup>	465 <sup>g</sup>	.47 <sup>i</sup>	.52 <sup>i</sup>	
ai19:0	17 <sup>a</sup>	15 <sup>a</sup>	16 <sup>a</sup>	.53 <sup>d</sup>	.33 <sup>f</sup>	.39 <sup>e</sup>	363 <sup>g</sup>	116 <sup>h</sup>	.44 <sup>i</sup>	.13 <sup>j</sup>	
Sum	43	62	54	1.28	1.31	1.34	1,056	1,082	1.27	1.20	
Unidentified sum	22	36	35	.69	.88	.79	466	724	.55	.81	
<b>Total saturated</b>	1,733	2,326	2,070	44.81	49.35	47.11	38,879	53,000	46.52	59.56	
<b>Unsaturated</b>											
<b>trans-Monoene</b>											
16:1 $\omega$ 7t											
18:1t	70 <sup>c</sup>	112 <sup>a</sup>	89 <sup>b</sup>	2.04 <sup>e</sup>	2.44 <sup>d</sup>	1.93 <sup>e</sup>	2,279 <sup>h</sup>	3,083 <sup>g</sup>	2.71 <sup>j</sup>	3.47 <sup>i</sup>	
Sum	70	112	89	2.04	2.44	1.93	2,279	3,083	2.71	3.47	
<b>cis-Monoene</b>											
14:1 $\omega$ 5c	27 <sup>a</sup>	27 <sup>a</sup>	56 <sup>a</sup>	.84 <sup>d</sup>	.58 <sup>d</sup>	1.02 <sup>d</sup>	718 <sup>g</sup>	275 <sup>h</sup>	.86 <sup>i</sup>	.31 <sup>j</sup>	
16:1 $\omega$ 7c	133 <sup>a</sup>	128 <sup>a</sup>	138 <sup>a</sup>	4.01 <sup>d</sup>	2.72 <sup>f</sup>	3.23 <sup>e</sup>	2,750 <sup>g</sup>	1,192 <sup>h</sup>	3.30 <sup>i</sup>	1.34 <sup>j</sup>	
17:1 $\omega$ 8c	54 <sup>b</sup>	58 <sup>ab</sup>	62 <sup>a</sup>	1.65 <sup>d</sup>	1.22 <sup>f</sup>	1.40 <sup>e</sup>	1,210 <sup>g</sup>	586 <sup>h</sup>	1.46 <sup>i</sup>	.66 <sup>j</sup>	
18:1 $\omega$ 9c	1,375 <sup>b</sup>	1,819 <sup>a</sup>	1,752 <sup>a</sup>	41.55 <sup>d</sup>	38.34 <sup>f</sup>	40.38 <sup>e</sup>	33,538 <sup>g</sup>	27,187 <sup>h</sup>	40.15 <sup>i</sup>	30.56 <sup>j</sup>	
18:1 $\omega$ 7c	60 <sup>b</sup>	68 <sup>a</sup>	66 <sup>a</sup>	1.83 <sup>d</sup>	1.47 <sup>f</sup>	1.54 <sup>e</sup>	1,354 <sup>g</sup>	906 <sup>h</sup>	1.62 <sup>i</sup>	1.02 <sup>j</sup>	
20:1 $\omega$ 9c	4 <sup>b</sup>	8 <sup>a</sup>	6 <sup>b</sup>	.16 <sup>d</sup>	.11 <sup>f</sup>	.13 <sup>e</sup>	155 <sup>g</sup>	103 <sup>h</sup>	.18 <sup>i</sup>	.11 <sup>j</sup>	
Sum	1,654	2,108	2,079	50.04	44.44	47.69	39,726	30,250	47.58	34.01	
<b>Diene</b>											
18:2 $\omega$ 6c	55 <sup>c</sup>	87 <sup>a</sup>	70 <sup>b</sup>	1.62 <sup>e</sup>	1.93 <sup>d</sup>	1.61 <sup>e</sup>	1,498 <sup>h</sup>	1,547 <sup>g</sup>	1.79 <sup>i</sup>	1.74 <sup>i</sup>	
20:2 $\omega$ 6c											
Sum	55	87	70	1.62	1.93	1.61	1,498	1,547	1.79	1.74	

Nondienoic polyene										
18:3 $\omega$ 3c	6 <sup>b</sup>	11 <sup>a</sup>	6 <sup>b</sup>	.19 <sup>e</sup>	.26 <sup>d</sup>	.16 <sup>f</sup>	181 <sup>h</sup>	147 <sup>g</sup>	.14 <sup>j</sup>	.16 <sup>i</sup>
20:3 $\omega$ 6c			8			.17				
20:4 $\omega$ 6c	6 <sup>a</sup>	7 <sup>a</sup>	21 <sup>a</sup>	.16	.19	.37				
20:5 $\omega$ 3c										
22:4 $\omega$ 6c										
22:5 $\omega$ 3c										
22:6 $\omega$ 3c										
Sum	12	18	35	.35	.45	.70	118	147	.14	.16
Unidentified sum	35	64	44	1.14	1.39	.96	1,072	971	1.27	1.05
Total monoene	1,724	2,220	2,169	52.08	46.88	49.62	42,005	33,334	50.29	37.48
Total $\omega$ 6 polyene	60	94	99	1.78	2.12	2.15	1,498	1,547	1.79	1.74
Total $\omega$ 3 polyene	6	11	6	.19	.26	.16	118	147	.14	.16
Total unsaturated	1,825	2,390	2,317	55.19	50.65	52.89	44,692	35,999	53.49	40.43
Total	3,558	4,716	4,387	100.00	100.00	100.00	83,571	88,999	100.01	99.99

<sup>a</sup>Bonferroni t-tests were used to make specific comparisons between fatty acids as a function of tissue site of grain-fed animals. The following four comparisons and associated separation symbols are used above: a,b,cST vs PM vs LM, mg/100 g tissue; d,e,fST vs PM vs LM, normalized; g,hSQ vs KD, mg/100 g tissue; i,jSQ vs KD, normalized. For a given row, values within each of the four comparisons are different (P<.05) if they have no letter in common. Values with no superscripts were not compared due to insufficient data. Tissue abbreviations: cf. footnote a, table 1; fatty acid abbreviations: cf. footnote a, table 2.

TABLE 5. FATTY ACID COMPOSITION<sup>a</sup> OF POLAR LIPID FRACTIONS AS A FUNCTION OF TISSUE SITE

Fatty acid	Muscle						Adipose			
	mg/100 g tissue			Normalized (%)			mg/100 g tissue		Normalized (%)	
	ST	PM	LM	ST	PM	LM	SQ	KD	SQ	KD
Saturated										
Normal										
14:0	2 <sup>a</sup>	3 <sup>a</sup>	2 <sup>a</sup>	.60 <sup>d</sup>	.39 <sup>e</sup>	.54 <sup>d</sup>	20 <sup>g</sup>	32 <sup>g</sup>	2.53 <sup>j</sup>	3.23 <sup>i</sup>
15:0	1 <sup>ab</sup>	2 <sup>a</sup>	1 <sup>b</sup>	.24 <sup>d</sup>	.26 <sup>d</sup>	.27 <sup>d</sup>	5 <sup>g</sup>	7 <sup>g</sup>	.62 <sup>i</sup>	.62 <sup>i</sup>
16:0	96 <sup>ab</sup>	102 <sup>a</sup>	79 <sup>b</sup>	18.87 <sup>d</sup>	15.82 <sup>e</sup>	18.72 <sup>d</sup>	171 <sup>g</sup>	226 <sup>g</sup>	23.10 <sup>i</sup>	24.43 <sup>i</sup>
17:0	4 <sup>b</sup>	4 <sup>a</sup>	3 <sup>b</sup>	.73 <sup>d</sup>	.66 <sup>d</sup>	.71 <sup>d</sup>	16 <sup>g</sup>	25 <sup>g</sup>	1.78 <sup>j</sup>	2.01 <sup>i</sup>
18:0	63 <sup>b</sup>	95 <sup>a</sup>	52 <sup>b</sup>	11.80 <sup>d</sup>	14.10 <sup>d</sup>	12.42 <sup>d</sup>	90 <sup>h</sup>	229 <sup>g</sup>	12.36 <sup>j</sup>	22.54 <sup>i</sup>
20:0	1 <sup>a</sup>	1 <sup>a</sup>	1 <sup>b</sup>	.23 <sup>d</sup>	.20 <sup>d</sup>	.22 <sup>d</sup>	3	3	.13	.16
Sum	168	207	139	32.48	31.43	32.88	305	522	40.53	53.00

<b>Branched</b>											
i15:0	<1			.23				1g	2g	.14j	.29i
ai15:0	<1		<1	.20		.15	1g	2g	.12j	.22i	
i16:0	<1	1	1	.15	.11	.10	1g	2g	.11	.15	
ai17:0	1 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a</sup>	.18 <sup>d</sup>	.13 <sup>d</sup>	.12 <sup>d</sup>	3g	5g	.36j	.54i	
ai19:0	1 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a</sup>	.19 <sup>d</sup>	.14 <sup>d</sup>	.12 <sup>d</sup>	4g	3g	.46i	.15j	
Sum	2	2	2	.96	.38	.49	9	13	1.19	1.36	
Unidentified sum	6	8	1	1.03	1.10	.28	9	21	2.25	3.52	
Total saturated	176	217	141	34.47	32.91	33.65	323	556	43.97	57.88	
<b>Unsaturated</b>											
<b>trans-Monoene</b>											
16:1 $\omega$ 7t	1 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a</sup>	.17 <sup>d</sup>	.16 <sup>d</sup>	.20 <sup>d</sup>		1			.24
18:1t	6 <sup>a</sup>	6 <sup>a</sup>	4 <sup>b</sup>	1.06 <sup>d</sup>	.93 <sup>d</sup>	1.00 <sup>d</sup>	24g	37g	2.56j	2.99i	
Sum	7	7	5	1.23	1.09	1.20	24	38	2.56	3.23	
<b>cis-Monoene</b>											
14:1 $\omega$ 5c	1	1	1	.26 <sup>d</sup>	.19 <sup>d</sup>	.16 <sup>d</sup>	5g	4g	.65i	.27i	
16:1 $\omega$ 7c	6 <sup>b</sup>	8 <sup>a</sup>	5 <sup>b</sup>	1.25 <sup>d</sup>	1.22 <sup>d</sup>	1.23 <sup>d</sup>	23g	14g	3.00i	1.32j	
17:1 $\omega$ 8c	4 <sup>b</sup>	6 <sup>a</sup>	4 <sup>b</sup>	.80 <sup>d</sup>	.86 <sup>d</sup>	.84 <sup>d</sup>	13g	10g	1.45i	1.27i	
18:1 $\omega$ 9c	97 <sup>b</sup>	136 <sup>a</sup>	90 <sup>b</sup>	19.08 <sup>d</sup>	20.18 <sup>d</sup>	20.99 <sup>d</sup>	267g	310g	34.52i	28.99j	
18:1 $\omega$ 7c	13 <sup>b</sup>	18 <sup>a</sup>	12 <sup>b</sup>	2.38 <sup>f</sup>	2.65 <sup>e</sup>	2.79 <sup>d</sup>	14g	12g	1.77i	1.16j	
20:1 $\omega$ 9c	4		<1	.66		.19	1	5	.14	.14	
Sum	125	169	112	24.42	25.10	26.19	322	355	41.53	33.16	
<b>Diene</b>											
18:2 $\omega$ 6c	110 <sup>b</sup>	153 <sup>a</sup>	94 <sup>b</sup>	18.63 <sup>e</sup>	22.13 <sup>d</sup>	21.17 <sup>d</sup>	20g	18g	3.19i	2.37i	
20:2 $\omega$ 6c	2 <sup>a</sup>	1 <sup>a</sup>	1 <sup>b</sup>	.24 <sup>d</sup>	.21 <sup>d</sup>	.24 <sup>d</sup>	1		.15		
Sum	112	155	94	18.87	22.34	21.41	21	18	3.34	2.37	
<b>Nondienoic polyene</b>											
18:3 $\omega$ 3c	5 <sup>a</sup>	5 <sup>a</sup>	3 <sup>b</sup>	.74 <sup>d</sup>	.73 <sup>d</sup>	.74 <sup>d</sup>	3h	5g	.29i	.34i	
20:3 $\omega$ 6c	13 <sup>b</sup>	16 <sup>a</sup>	9 <sup>c</sup>	2.12 <sup>d</sup>	2.21 <sup>d</sup>	2.10 <sup>d</sup>	4g	1g	1.09i	.39j	
20:4 $\omega$ 6c	52 <sup>a</sup>	54 <sup>a</sup>	33 <sup>b</sup>	8.08 <sup>d</sup>	7.53 <sup>d</sup>	7.13 <sup>d</sup>	7g	1h	2.32i	.61i	
20:5 $\omega$ 3c	11 <sup>a</sup>	8 <sup>b</sup>	5 <sup>c</sup>	1.71 <sup>d</sup>	1.15 <sup>d</sup>	1.05 <sup>d</sup>	0		.27		
22:4 $\omega$ 6c	6 <sup>a</sup>	6 <sup>a</sup>	4 <sup>b</sup>	.87 <sup>d</sup>	.89 <sup>d</sup>	.92 <sup>d</sup>	1		.44		
22:5 $\omega$ 3c	22 <sup>a</sup>	18 <sup>b</sup>	11 <sup>c</sup>	3.32 <sup>d</sup>	2.52 <sup>e</sup>	2.35 <sup>e</sup>	3		1.08		
22:6 $\omega$ 3c	3 <sup>a</sup>	2 <sup>a</sup>	1 <sup>b</sup>	.43 <sup>d</sup>	.30 <sup>d</sup>	.25 <sup>e</sup>	1		.27		
Sum	111	111	67	17.27	15.33	14.55	19	15	5.75	1.34	
Unidentified sum	16	22	11	3.75	3.23	3.00	30	32	2.84	2.00	
Total monoene	132	176	117	25.65	26.19	27.39	346	393	44.09	36.39	
Total $\omega$ 6 polyene	183	231	141	29.94	32.97	31.56	33	20	7.19	3.37	
Total $\omega$ 3 polyene	40	34	21	6.20	4.70	4.40	7	13	1.90	.34	
Total unsaturated	371	463	290	65.54	67.09	66.35	416	457	56.02	42.10	
Total	547	671	432	100.01	100.00	100.00	740	1,013	99.99	99.98	

<sup>a</sup>See footnote a, table 4.

parisons are presented in two independent sets—ST<sub>F</sub> vs ST<sub>G</sub>, SQ<sub>F</sub> vs SQ<sub>G</sub>—in table 2 (neutral lipid profiles) and table 3 (polar lipid profiles).

*Normal Saturated Fatty Acids.* The pattern for the normal saturated fatty acids is instructive of why the data are presented in two formats. In the neutral lipid fraction (table 2), these fatty acids predominate in ST<sub>G</sub> over ST<sub>F</sub> in the gravimetric data, whereas the inverse pattern occurs (ST<sub>F</sub> over ST<sub>G</sub>) for the normalized data. For example, 100 g tissue of grain-fed beef yields 360 mg 18:0 (stearic acid) as opposed to 207 mg from an equal portion of tissue of forage-fed animals. On the other hand, the total fatty acid is only 10.63% 18:0 in tissue of grain-fed beef, as opposed to 14.41% in tissue of forage-fed beef. The apparent contradiction in the two formats arises due to the relative leanness of tissue of forage-fed animals [2.17% neutral lipid for ST<sub>F</sub> vs 3.82% for ST<sub>G</sub> (table 1)]. Thus, the infiltrated fat and its accompanying fatty acids are more highly saturated in the forage-fed beef but are present in lesser amounts than in the grain-fed beef. The pattern seen for 18:0 is more or less typical of the normal saturates for both muscle and, to a lesser extent, adipose. The shifting of data format often eliminates a statistically significant difference (cf. 16:0 for ST or SQ). In the profiles of the polar lipid fractions (table 3), the ST comparisons present no significant differences; the SQ comparisons are essentially the same as shown by the SQ neutral profiles (table 2), indicative of the high carryover of neutral lipid into SQ's polar fraction. Our observations on the normal saturates corroborate with the conclusions drawn from gravimetric data by Miller et al. (1981), and conclusions from normalized data by Brown et al. (1979), Montgomery and Bidner (1979), Westerling and Hedrick (1979) and Melton et al. (1982).

*Branched Saturated Fatty Acids.* These minor fatty acids tend to appear in greater amounts in tissue of forage-fed beef than in tissue of grain-fed beef (table 2). Among the individual branched acids, significant differences were observed in the neutral lipid fractions from both muscle and adipose tissue (table 2). In the polar lipid fractions, such differences were absent for muscle and reflected the neutral lipid carryover for adipose (table 3). Our results are in agreement with those of Montgomery and Bidner (1979; adipose, nor-

malized profile) and with those of Miller et al. (1981; muscle, gravimetric profile). Smith et al. (1979) suggested that branched fatty acids arise from the digestion of ruminant microorganisms, and that these fatty acids predominate in forage-fed animals because the contribution from dietary lipids of feed is minimal.

*trans-Monoenoic Fatty Acids.* Except for the neutral muscle data (table 2), all forage samples contained more trans acids than did their grain counterparts (tables 2 and 3). Our findings with muscle agree with those of Miller et al. (1981), who found that 18:1t predominated in muscle of grain-fed beef in their gravimetric tabulations; recalculation of their data to normalized values substantiates our normalized findings as well.

*cis-Monoenoic Fatty Acids.* In all neutral lipid fractions (table 2), cis-monoenes [including 18:1 $\omega$ 9c (oleic acid), the most prevalent fatty acid in beef] predominated in grain-fed over forage-fed beef. In the polar lipid fractions (table 3), only minimal differences were observed for muscle; adipose patterns again reflected neutral lipid carryover into the polar fraction. Our findings agree, with the exceptions noted below, with those of Brown et al. (1979), Westerling and Hedrick (1979), Miller et al. (1981) and Melton et al. (1982). In contrast to these reports, normalized reports of Montgomery and Bidner (1979) showed higher percentages of 14:1, 16:1 and 18:1 in adipose of forage-fed than grain-fed animals. We note this exception for 14:1 and 16:1, but not for 18:1.

*Dienoic Fatty Acids.* With the exception of the adipose gravimetric data, more of this class of fatty acids is found in the polar (table 3) than in the neutral lipid fractions (table 2). The major component of this class, 18:2 $\omega$ 6c (linoleic acid), is an essential fatty acid in human diets and the biochemical predecessor of the other  $\omega$ 6 polyenes shown in our profiles. Generally, larger amounts of the dienes were found in tissue of grain-fed than in that of forage-fed steers (tables 2 and 3), a finding in agreement with other investigators (Miller et al., 1981; Melton et al., 1982).

*Nondienoic Polyenoic Fatty Acids.* The distribution of these acids between the neutral (table 2) and polar lipid fractions (table 3) displays the same pattern noted above for the dienes. One component of this class, 20:4 $\omega$ 6c (arachidonic acid) is an essential dietary acid. The data for 20:4 show no significant differ-

ences at all between tissue of forage-fed and grain-fed steers (tables 2 and 3), as opposed to the findings of Westerling and Hedrick (1979) and Melton et al. (1982). All components of this group of fatty acids, notably 18:3 $\omega$ 3c (linolenic acid), are highly prone to oxidation, and therefore are associated with off-flavors in meat of forage-fed animals (Bidner et al., 1975; Brown et al., 1979). Our normalized and gravimetric data for the sum of nondienoic polyenes in ST muscle show no difference in the polar fraction as a function of dietary regimen (table 3). However, differences were seen in data from the neutral lipid fractions. These differences were not apparent on examination of the gravimetric data; amounts of these fatty acids vary little ( $ST_F = 11$  mg,  $ST_G = 12$  mg). The differences were only apparent by examining the normalized data ( $ST_F = 1.09\%$ ,  $ST_G = .35\%$ ); the normalized data are related to the concentration of these fatty acids in the fat alone, instead of the concentration in the entire tissue.

Although our data are expressed as separate profiles of neutral and polar lipid fractions, total lipid profiles may be constructed by consolidating the reports of the neutral and polar fractions. For gravimetric data, this may be done simply by adding the two values. Thus for  $ST_F$ , nondienoic polyenes amount to 114 mg ( $103 + 11$ ) vs the similar amount of 123 mg for  $ST_G$ . Total lipid profiles from the normalized data may be constructed by using the polar factors of table 1. Thus,

$$\begin{aligned} & (\text{polar factor})(\% \text{ of polar lipid}) \\ & + (1 - \text{polar factor})(\% \text{ of neutral lipid}) \\ & = (\% \text{ of total lipid}). \end{aligned}$$

Substituting the appropriate data for  $ST_F$ ,

$$\begin{aligned} & (.2798)(17.32) + (1 - .2798)(1.09) \\ & = 5.63\% \end{aligned}$$

of total lipid as nondienoic polyene vs 2.79% for  $ST_G$ . The pattern  $ST_F > ST_G$  from the consolidated data is the same as seen for the neutral lipid data.

Thus, the lipid from  $ST_F$  is more concentrated in nondienoic polyene than is the lipid from  $ST_G$ . For the adipose tissues studied, both the lipid and the whole tissue (i.e., normalized and gravimetric data) of  $SQ_F$  are more concentrated in these fatty acids than the lipid and tissue, respectively, of  $SQ_G$ .

Within this class of fatty acids, the component that shows the greatest statistical difference as a function of dietary regimen is 18:3 $\omega$ 3c (linolenic acid; tables 2 and 3). In almost every comparison, 18:3 is found in greater amounts in tissue of forage-fed than in that of grain-fed beef. Our results with 18:3 agree with the previous findings of Westerling and Hedrick (1979), Montgomery and Bidner (1979), Miller et al. (1981) and Melton et al. (1982). High 18:3 content in tissue of forage-fed beef results from ingestion of forage grasses, whose 18:3 content is 50 to 60% of the total fatty acids found in the leaf (Garton, 1965).

*Tissue vs Tissue, All-Grain.* Comparisons are presented in two independent sets— $ST_G$  vs  $PM_G$  vs  $LM_G$ ,  $SQ_G$  vs  $KD_G$ —in table 4 (neutral lipid profiles) and table 5 (polar lipid profiles).

*Normal and Branched Saturated Fatty Acids.* For virtually every fatty acid in these classes, normalized data from the neutral lipid fractions (table 4) indicate increasing percentages with increasing fattiness of the tissue ( $ST > PM > LM$ ;  $KD > SQ$ ). These neutral lipid fractions in muscle reflect the composition of the contiguous intermuscular adipose tissue. For comparisons, note that the normalized neutral lipid profile of ST resembles the profile of the attached adipose, SQ. Because the fattiest tissues contain the highest percentages of saturated fatty acids, the gravimetric data show the same pattern as the normalized data. In the polar lipid profiles (table 5), few differences are seen in the muscle data, and the adipose data again reflect the considerable carryover of neutral lipid into the polar lipid fraction. Our findings may be compared to those of Terrell and Bray (1969), who also noted that PM ranked high in saturated fatty acid content relative to triceps brachii (TB) and transversus abdominis (TA) muscle.

*Monoenoic Fatty Acids.* With the exception of the trans-monoenes, these fatty acids show essentially the opposite pattern of the saturated fatty acids, i.e., increasing percentages with increasing leanness of the tissues. As in the forage-grain comparisons, gravimetric reports show an inverse trend, due to the bias imparted by the fattiness of the tissue. Terrell and Bray (1969) also noted the deficiency of PM tissue in these monoenes, relative to TB and TA muscle.

*Polyenoic Fatty Acids (Dienes and Nondienoic Polyenes).* Although the polar lipid fractions of muscle and adipose contain more of these fatty acids than do the neutral lipid

fractions, the contribution by the neutral lipids is substantial. Dienes (mainly 18:2 $\omega$ 6) were always found in larger amounts than nondienoic polyenes (often mainly 20:4 $\omega$ 6, not 18:3 $\omega$ 3). In every muscle comparison (tables 4 and 5), the dienes were found in greater amounts in PM than in ST or LM. Although PM ranked highest in our study, Terrell and Bray (1969) found that PM was lower in 18:2 relative to TB and TA. The large contribution of the diene content to the  $\omega$ 6 polyene content (the essential fatty acids) and to the total polyene content again makes PM the most enriched in these latter two classes, relative to ST and LM. Although definitive trends were observed for the diene content of muscle, no trend was seen among the nondienoic polyenes.

### Conclusions

The gravimetric data are most relevant for nutritional studies, because the mg amounts per unit weight of tissue essentially are "dosages." Most attention has been given to dietary saturated fat and to the essential fatty acids (the  $\omega$ 6 series), with additional concern over branched and trans content. In the forage-grain study, tissue of grain-fed beef presents the highest dosage of both saturated and essential fatty acids. Larger amounts of branched and trans acids are found in adipose of forage-fed than in that of grain-fed beef, whereas in muscle, branched acids are found in similar amounts in tissue of both forage and grain-fed animals and trans acids predominate in tissue of grain-fed beef. In the tissue-by-tissue study, PM muscle offers the highest dosage of all these categories of fatty acids. Likewise, KD adipose offers the most saturates and SQ the most trans acid, but branched and essential fatty acids are found in similar amounts in both types of adipose tissue.

The normalized data are most relevant to the properties of the fat. Saturated fatty acids impart hardness, and are always most prevalent in forage-fed beef. In the tissue-by-tissue comparisons, saturates are concentrated in PM muscle and KD adipose. Nondienoic polyenes are most prone to oxidative rancidity and concomitant off-flavor and these, too, are most prevalent in tissues of forage-fed animals. In the tissue-by-tissue comparisons, they predominate in ST muscle but are distributed similarly in SQ and KD adipose. Tissues noted for their high polyene content, our findings suggest, merit great care in their handling and storage.

### Literature Cited

- Bidner, T. D. 1975. A comparison of forage-finished and grain-finished beef. *Reciprocal Meat Conf.* 28:201.
- Brown, H. G., S. L. Melton, M. J. Riemann and W. R. Backus. 1979. Effects of energy intake and feed source on chemical changes and flavor of ground beef during frozen storage. *J. Anim. Sci.* 48:338.
- Dwivedi, B. K. 1975. Meat flavor. *CRC Crit. Rev. Food Technol.* 4:487.
- Garton, G. A. 1965. The digestion and assimilation of lipids. In: R. W. Dougherty (Ed.) *International Symp. on the Physiology of Digestion in the Ruminant.* pp 390-398. Butterworth, Washington, DC.
- Harrison, A. R., M. E. Smith, D. M. Allen, M. C. Hunt, C. L. Kastner and D. H. Kropf. 1978. Nutritional regime effects on quality and yield characteristics of beef. *J. Anim. Sci.* 47:383.
- Kinsella, J. E., L. Posati, J. Weihrauch and B. Anderson. 1975. Lipids in foods: Problems and procedures in collating data. *Crit. Rev. Food Technol.* 5:299.
- Marmar, W. N. and R. J. Maxwell. 1981. Dry column method for the quantitative extraction and simultaneous class separation of lipids from muscle tissue. *Lipids* 16:365.
- Marmar, W. N., R. J. Maxwell and J. G. Phillips. 1983. Systematic management and analysis of fatty acid data from multiple tissue samples. *Lipids* 18:460.
- Maxwell, R. J. and W. N. Marmar. 1983. Systematic protocol for the accumulation of fatty acid data from multiple tissue samples: Tissue handling, lipid extraction and class separation, and capillary gas chromatographic analysis. *Lipids* 18:453.
- Melton, S. L., N. Amiri, G. W. Davis and W. R. Backus. 1982. Flavor and chemical characteristics of ground beef from grass-, forage-grain-, and grain-finished steers. *J. Anim. Sci.* 55:77.
- Miller, R. G., Jr. 1981. *Simultaneous Statistical Inference.* Springer-Verlag, New York, Heidelberg, Berlin. pp 67-70.
- Miller, G. J., M. L. Masor and M. L. Riley. 1981. Intramuscular lipids and triglyceride structures in range and feedlot steers. *J. Food Sci.* 46:1333.
- Montgomery, R. E. and T. D. Bidner. 1979. Palatability and fatty acid composition of forage and grain finished beef. *J. Anim. Sci.* 49(Suppl. 1):53.
- Moody, W. G. 1976. Quantitative and qualitative differences in beef from various energy regimes. *Proc. 29th Annu. Recip. Meat Conf.* p 128.
- Reagan, J. O., J. A. Carpenter, F. T. Bauer and R. S. Lowrey. 1977. Packaging and palatability characteristics of grass and grass-grain fed beef. *J. Anim. Sci.* 45:716.
- Roberts, W. K. 1966. Effects of diet, degree of fatness and sex upon fatty acid composition of cattle tissues. *Can. J. Anim. Sci.* 46:181.
- Rumsey, T. S., R. R. Oltjen, K. P. Bovard and B. M. Priode. 1972. Influence of widely diverse finishing regimens and breeding on depot fat composition in beef cattle. *J. Anim. Sci.* 35:1069.
- Smith, A., A. G. Calder, A. K. Lough and W.R.H.

- Duncan. 1979. Identification of methyl-branched fatty acids from the triacylglycerols of subcutaneous adipose tissue of lambs. *Lipids* 14: 953.
- Terrell, R. N. and R. W. Bray. 1969. Influence of sex, liveweight and anatomical location on bovine lipids. III. Fatty acid composition of the neutral and phospholipid fractions from three muscles. *J. Anim. Sci.* 29:288.
- Westerling, D. B. and H. B. Hedrick. 1979. Fatty acid composition of bovine lipids as influenced by diet, sex, and anatomical location and relationship to sensory characteristics. *J. Anim. Sci.* 48:1343.
- Williams, J. E., D. G. Wagner, L. E. Walters, G. W. Horn, G. R. Waller, P. L. Sims and J. J. Guenther. 1983. Effect of production systems on performance, body composition and lipid and mineral profiles of soft tissue in cattle. *J. Anim. Sci.* 57: 1020.