Effects of conventional and grass-feeding systems on the nutrient composition of beef[1]

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ABSTRACT: The objectives of this study were to determine the nutrient composition of grass-fed beef in the United States for inclusion in the USDA National Nutrient Database for Standard Reference, and to compare the fatty acid composition of grass-fed and conventionally fed (control) beef. Ground beef (GB) and strip steaks (SS) were collected on 3 separate occasions from 15 grass-fed beef producers that represented 13 different states, whereas control beef samples were collected from 3 regions (Ohio, South Dakota, and Texas) of the United States on 3 separate occasions. Concentrations of minerals, choline, vitamin B_{12}, and thiamine were determined for grass-fed beef samples. Grass-fed GB samples had less Mg, P, and K ($P < 0.05$), and more Na, Zn, and vitamin B_{12} ($P < 0.05$) than SS samples. Fat color, marbling, and pH were assessed for grass-fed and control SS. Subjective evaluation of the SS indicated that grass-fed beef had fat that was more yellow in color than control beef. Percentages of total fat, total cholesterol, and fatty acids along with *trans* fatty acids and CLA were determined for grass-fed and control SS and GB. Grass-fed SS had less total fat than control SS ($P = 0.001$), but both grass-fed and control SS were considered lean, because their total fat content was 4.3% or less. For both GB and SS, grass-fed beef had significantly less ($P = 0.001$ and $P = 0.023$, respectively) content of MUFA and a greater content of SFA, n-3 fatty acids, CLA, and *trans*-vaccenic acid than did the control samples. Concentrations of PUFA, *trans* fatty acids, n-6 fatty acids, and cholesterol did not differ between grass-fed and control ground beef. *Trans*-vaccenic acid (*trans*-11 18:1) made up the greatest concentration of the total *trans* fats in grass-fed beef, whereas CLA accounted for approximately 15% of the total *trans* fats. Although the fatty acid composition of grass-fed and conventionally fed beef was different, conclusions on the possible effects of these differences on human health cannot be made without further investigation.

Key words: beef, conjugated linoleic acid, conventionally fed, fatty acid, grass-fed, nutrient composition

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INTRODUCTION

Monounsaturated fatty acids and SFA comprise the largest percentages of fatty acids in beef fat. Furthermore, beef fats are among the richest natural sources of CLA (Chin et al., 1992) and *trans*-vaccenic acid, which has been shown to have health benefits (Belury, 2002; Bhattacharya et al., 2006; Huth, 2007). Monounsaturated and n-3 fatty acids aid in reducing the risk of heart disease, whereas some SFA increase serum cholesterol levels (Groff and Gropper, 1999).

The types of forage fed to cattle affect gains and carcass characteristics (Allen et al., 1996), and crop variety, season, year, and geographic location are well known to affect the nutrient content of feedstuffs (Preston, 2004). Therefore, grass-fed beef production in the United States is highly variable because of the variety of genetics, forages, and management practices used, which affect the fatty acid composition of beef (Leonhardt and Wenk, 1997).

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Previous research has shown that forage-finished cattle produce beef with more CLA and n-3 fatty acids compared with grain-finished beef (Marmer et al., 1984; French et al., 2000). Some studies found that grass-fed beef had a decreased concentration of MUFA and a greater concentration of SFA compared with grain-fed beef (Melton et al., 1982; Marmer et al., 1984); however, one study found that grass-fed beef had less SFA and more MUFA than grain-fed beef (French et al., 2000).

There has been an increase in demand for natural meat products, such as grass-fed beef, partially as a result of consumer interest in the fat content of foods (Food Marketing Institute, 2005). Because of the known variability in grass-fed beef production systems, it is essential to provide consumers with nutrient data for grass-fed beef so an educated purchasing decision can be made. Therefore, the objectives of this study were to determine the nutrient composition of grass-fed beef in the United States for inclusion in the USDA National Nutrient Database for Standard Reference (**SR**) and to compare the fatty acid profile of grass-fed and conventionally fed beef.

MATERIALS AND METHODS

Protocols for preparing and compositing the meat samples, along with a quality control plan specific to each nutrient to be analyzed, were developed in accordance with USDA Nutrient Data Laboratory (**NDL**) guidelines. Therefore, all design and sampling procedures for this study were approved by USDA-NDL.

Grass-fed producers completed a screening questionnaire to determine whether they qualified to participate in this study. Only producers that indicated 100% of the cattle diets were made up of native grasses, forages, or cut grasses or forages were allowed to participate. Producers were also screened to determine the types of vitamin and mineral supplements that were provided to their cattle. The majority of the producers in this study indicated using a typical vitamin and mineral supplement, whereas others reported using no supplements at all. Furthermore, producers selected were full-time grass-fed beef producers who were actively selling and marketing their product to restaurants, local retailers, private meat markets, and via the Internet. The key objective to this study was to obtain the most representative sampling of US grass-fed beef to produce compositional data for release in the SR. The SR provides compositional data for foods commonly consumed by Americans. All efforts were made to ensure that the sampling of grass-fed beef in this study was nationally representative of products available to the US population.

The second objective of this study was to compare the fatty acid composition of the grass-fed beef samples with conventional beef (control) in the United States Therefore, control samples were also collected. Conventional beef feeding systems are very standardized throughout the United States, whereas grass-feeding is not. Therefore, control samples were collected from 3 regions of the country, whereas grass-fed samples were collected from 15 different producers.

Ground beef and strip steaks (derived from IMPS/NAMP 180 Beef Loin, Strip Loin) were collected from 15 grass-fed beef producers representing 13 different states (Alabama, Arkansas, California, Colorado, Georgia, Idaho, Kentucky, Minnesota, Missouri, Montana, New Mexico, Texas, and Virginia) on 3 different occasions. Similarly, control beef samples were collected by university personnel from the retail meat case or university meat laboratory in each of 3 different regions of the country (Lubbock, TX; Brookings, SD; Columbus, OH) on 3 different occasions.

A sample collection protocol was provided to all producers and universities that obtained samples for this study. The sample collection protocol required that 2 steaks from 3 different animals be collected by each producer or university on each of 3 different occasions. All steaks were cut 2.54-cm thick from the 13th rib position of the strip loin (IMPS/NAMP 180 Beef Loin, Strip Loin). Likewise, 454 g of ground beef targeting 85% lean and 15% fat (85/15) was to be collected by each producer or university from 3 different carcasses on each of 3 different occasions. However, the specified lean-to-fat ratio (85/15) was not available from all grass-fed beef producers. When this occurred, the producer was asked to provide samples of the next leanest ground beef (i.e., 88/12) they had available. Furthermore, 3 producers were unable to provide samples for each sampling period.

All samples were vacuum-packaged with proper identification, and shipped overnight in an insulated container on dry ice to the Texas Tech University Gordon W. Davis Meat Science Laboratory. On delivery, the condition of the package and its contents were inspected. Surface temperature of the meat samples was recorded to ensure that temperature was maintained at less than −2°C during shipping. Sample weights were also recorded at the time of receipt. Samples were stored at −12°C until sample preparation occurred. Samples that were obtained in Lubbock were purchased fresh (unfrozen) and were identified, vacuum-packaged, weighed, and frozen at the Texas Tech University Meat Laboratory. All samples were stored and processed in a dark environment to decrease vitamin B deterioration.

Ground Beef Samples

Frozen packages of ground beef were placed in a cooler at 0 to 4°C to thaw before sample preparation. Thawed ground beef samples were frozen in liquid nitrogen and homogenized in a Blixer food processor (model BX 6/6V; Robot Coupe USA Inc., Jackson, MS) at 1,500 rpm for 10 s and then at 3,500 rpm for 30 s. If a sample did not reach homogeneity, the sample was

homogenized for an additional 30 s at 3,500 rpm. Once homogeneity was accomplished, aliquots of homogenized samples were placed in labeled Whirl-Pak bags (Nasco, Fort Atkinson, WI). All samples were double bagged. Samples were stored at −80°C until chemical analysis occurred.

Strip Steak Samples

Packages of strip steaks were placed in a cooler at 0 to 4°C for 24 h before sample preparation. After thawing, strip steaks were removed from their vacuum packages, placed on a plastic tray, covered with oxygen-permeable film, and stored in a dark cooler for 90 min before quality assessment. Subjective marbling and lean maturity were evaluated for each sample by using USDA Quality Grading standards (USDA, 1997). A subjective fat color score was evaluated for each sample based on the Japanese Meat Grading Association Beef Carcass Grading Standards (Japan Meat Grading Association, 2000). Additionally, the pH of the strip steaks was measured by using a calibrated IQ 150 hand-held pH meter (IQ Scientific Instruments Inc., Carlsbad, CA). After the quality assessment, strip steaks were weighed and dissected. The mean of each quality characteristic within a single sample set from a producer or location was analyzed.

The lean, fat, and refuse (connective tissue and scrap) of each steak was separated and weighed individually. Intermuscular and subcutaneous fat, connective tissue, and any other muscles present were separated from the LM. Intermuscular and subcutaneous fat were combined for chemical analyses. Any other muscles and connective tissue that were present were considered scrap and discarded. Cubed strip steak samples were frozen in liquid N and homogenized in a Blixer food processor according to the same protocol as ground beef samples. Aliquots of homogenized samples were placed in labeled Whirl-Pak bags, and all samples were double bagged. Samples were stored at −80°C until analysis.

Chemical Analyses

Proximate analyses (percentage of ether-extractable fat, protein, and moisture) were conducted at Texas Tech University in the Animal and Food Science Analytical Laboratory. Determination of the percentage of ether extract of each sample was conducted by using the Soxhlet method according to method 991.36 (AOAC, 1995). The percentage of protein in the samples was determined by combustion by using a Leco FP 2000 instrument (St. Joseph, MI) following AOAC method 992.15 (Crude Protein in Meat and Meat Products Combustion, AOAC, 1995). The percentage of moisture of the samples was analyzed by oven-drying according to AOAC method 8.2.1.1 (AOAC, 1995), and the percentage of ash was determined by the difference.

Fatty acids were determined according to AOAC method 996.06 by Covance Laboratory (Madison, WI). Lipids were extracted from 3 g of sample by refluxing for 5 h with pentane by using a Soxhlet extraction apparatus according to AOAC methods 948.22 and 960.39 (modified; AOAC, 2000). They were then saponified with 0.5 *N* methanolic sodium hydroxide and methylated with 14% BF_3 methanol. Fatty acid content was determined by gas chromatography with an SP-2560 column (100 m × 0.25 mm × 0.2 μm film thickness) with an injection port temperature of 250°C, a split ratio of 1:100, a flame-ionization detector set at 300°C: hydrogen 30 mL/min, air 300 mL/min, makeup helium 30 mL/min, hydrogen carrier gas, and 1.2 mL/min constant flow. The oven temperature program was set as follows: 170°C, hold 5 min; increase 2°C/min to 190°C, hold 5 min; increase 10°C/min to 210°C, hold 5 min; increase 10°C/min to 230°C, hold 10 min. The internal standard used depended on the chain length of the fatty acid in question. Tridecanoic methyl ester (C13:0) was used as the internal standard for regular fatty acids and C23:0 was the internal standard used for long-chain fatty acids. Standards were injected with each analysis run, and response factors were calculated. A 5-point linear regression curve based on the response factors of the injected standard solutions was used to calculate the concentration of the fatty acids in the sample.

Cholesterol was analyzed by method 994.10 (Direct Saponification–Gas Chromotographic Method; AOAC, 2000) by the Covance Laboratory. Samples were saponified in 8 mL of 50% KOH solution and 40 mL of EtOH for 90 min. Saponified samples were rinsed with 60 mL of EtOH, and 100 mL of toluene was then added and mixed vigorously in a separatory funnel. After separation and removal of the polar layer (which occurs after every shake), 40 mL of 0.5 *N* KOH was added and given a light shake. Three separate additions of 40 mL of DiH_2O occurs with a light shake, hard shake, hard shake sequence. The toluene passes through a column of Na_2SOH salt into a flask, which is then capped to complete the extraction. Cholesterol was determined by gas chromatography by using a HP-5 column (length of 25 m, a 0.32-mm internal thickness, and a 0.17-mm film thickness), with helium as the carrier gas (2.1 mL/min with a carrier pressure at 20 atm), and a flame-ionization detector (300°C, 348 mL/min of helium flow at 39.4 mL/min and makeup gas flow at 30.4 mL/min). A split injector was used, with a split ratio of 7.4:1 and a 1.0-mL injection volume with a run time of 40 min.

Grass-fed beef samples were analyzed for choline at the University of North Carolina by extracting the choline compounds and quantifying by liquid chromatography-electrospray ionization-isotope dilution mass spectrometry (Koc et al., 2002). Samples were analyzed for betaine and 5 choline-contributing compounds: free choline, glycerophosphocholine, phosphocholine, phosphatidylcholine, and sphingomyelin (Howe et al., 2004). Total choline content is calculated as the sum of these choline-contributing metabolites (free choline, glycerophosphocholine, phosphocholine, phosphatidylcholine, and sphingomyelin; Howe et al., 2004). Covance Labo-

Table 1. Hot carcass weight and age of grass-fed beef animals at slaughter and the aging time of their strip steaks

Characteristic	n	Grass-fed	Minimum	Maximum
Age, mo	104	23	16	30
HCW, kg	104	271	197	397
Age time, d[1]	101[2]	20	2	41

[1]Number of days from slaughter to freezing of beef.
[2]The aging time for 3 grass-fed beef animals was not available, making n = 101.

ratory analyzed the samples for thiamine, vitamin B_{12}, Se, and other minerals (Ca, Cu, Fe, Mg, Mn, P, K, Na, and Zn) following AOAC methods 942.23, 960.46, 986.15, and 984.27, respectively (AOAC, 2000).

Quality Control

To validate all analytical procedures, quality control was monitored by inclusion of certified reference materials and blind duplicates into the sampling stream. Blind duplicates were selected randomly from study samples, aliquoted, and labeled according study protocol. A blind duplicate was prepared for every 10 study samples to be analyzed. If the CV of the study sample and its respective blind duplicate was greater than 10%, the data were considered invalid and reanalyzed. No CV was greater than 10% in this study.

National Institute of Standards and Technology (**NIST**) Standard Reference Materials (**SRM**) required by USDA-NDL were also prepared for analysis. The SRM identifications were also blinded to the analysts and were analyzed along with study samples. Chemical analyses were considered valid by USDA-NDL when a SRM was within the SE of the certified value for the respective SRM. Meat homogenate, SRM 1546 (NIST, 2004a), was required to be analyzed for all nutrients except Se. Baby food composite, SRM 2383 (NIST, 2002), was used to validate the Se analysis. Infant formula, SRM 1846 (NIST, 2004b), was used to validate determinations of vitamin B_{12} and choline, and peanut butter, SRM 2387 (NIST, 2003), was used for evaluation of thiamine values.

In addition to the required SRM, Beechnut Beef and Poultry baby food homogenates were analyzed along with all study samples for all chemical analyses according to the USDA-NDL protocol. These products do not have a certified value, but do have a database of previous values within which the analyzed samples must fall to be considered valid. All data were validated by USDA-NDL staff.

Data Analyses

Breed type, forage type, management systems, and geographical location were different among producers providing samples. Because all these factors can affect the nutrient composition of the meat, they are considered nuisance variables. Furthermore, this study was not a randomized controlled study because it was impossible to randomly assign treatment to the animals. Consequently, the F-statistic was not able to be used to assess the significance of the treatment differences. Therefore, permutation analysis (randomized test) was used to test the significance of the treatments, because it can be used when the F-statistic cannot. All permutation analyses between grass-fed and control beef samples were performed using Minitab Release 14 (Minitab Inc., State College, PA). In this permutation analysis, 1,000 permuted differences were calculated for each comparison to determine whether the magnitude of difference between actual means was a result of chance (variation of data) or whether it was an actual difference that was not likely the result of chance. The permutation analysis *P*-value was determined by calculating the proportion of permuted differences that were greater than the actual difference between the original means.

Quality characteristics along with percentages of moisture, fat, protein, and ash were statistically evaluated by using sampling period (replication) for each producer as the experimental unit. Vitamin and mineral analysis of the grass-fed beef samples were evaluated by composites of producers. Seven composites from individual producers and 4 composites of 2 producers each (paired on similar genetics, management practices, and region). Cholesterol and fatty acid data were analyzed by using producer or university as the experimental unit.

RESULTS AND DISCUSSION

Grass-fed cattle in this study were harvested, on average, at 23 mo of age; however, there was a wide range in the age at harvest (Table 1). The average carcass weight of the grass-fed cattle was 271 kg, which was substantially less than the average carcass weight of conventional cattle harvested in the United States. According to USDA Market Reports (USDA, 2008), the average dressed weight of cattle at slaughter was 360 kg in 2005, which is greater than the 5-yr average of 341 kg (USDA, 2008).

Average aging time of the grass-fed strip steaks in this study was 20 d. This is very similar to the 1998 National Beef Tenderness Survey, which found the average postfabrication aging time for subprimals at the retail level to be 19 d (Brooks et al., 2000). Nonethe-

Table 2. Means and SE of assessment of fat color, marbling scores, and pH of control and grass-fed beef strip steaks

	Control			Grass-fed			
Characteristic	n[1]	Mean	SE	n[2]	Mean	SE	*P*-value
Fat color[3]	9	2.0	0.51	41	3.7	0.16	<0.001
Marbling[4]	9	503	17.3	44	420	7.8	<0.001
pH	9	5.6	0.04	44	5.7	0.02	0.525

[1]n represents 3 sample composites from each of 3 different regions of the country.

[2]n represents sample composites from each of 15 grass-fed producers. The n for fat color is 41 because there was no fat to assess color on 2 sample composites.

[3]Fat color score based on Japanese Beef Carcass Grading Standards: 1 = whitest/lightest colored to 7 = extremely yellow/darkest colored.

[4]Marbling score based on USDA Beef Carcass Grading Standards (USDA, 1997): 300 = Slight[00], 400 = Small[00], 500 = Modest[00].

less, the 2005 National Beef Tenderness Survey found that the average postfabrication aging time for retail subprimals was 23 d (NCBA, 2006). Aging fresh meat allows protein degradation to occur. Therefore, aging time and toughness are negatively correlated (Brooks et al., 2000). The longer cattle are finished on grain, the more tender their meat becomes (Leander et al., 1978; Bennett et al., 1995). Ruhland (2004) and Moeller (1997) indicated that consumers would choose to eat beef more often if they knew it was tender and had a more consistent eating quality. Furthermore, Boleman et al. (1997) found that consumers can differentiate between different tenderness groups of beef and are willing to pay for increased tenderness.

Quality evaluation (Table 2) of the beef strip steaks indicated that grass-fed beef had more yellow fat and less marbling than did the grain-fed (control) beef. These results were similar to previous studies, which also reported grass-fed beef having a lesser marbling score (Bidner et al., 1976; Reagan et al., 1977; Crouse and Seideman, 1984) and fat that was more yellow in color than beef from a conventional feeding system (Bidner et al., 1976; Crouse and Seideman, 1984). These differences can be attributed to the variance in the cattle diets. Fat color can be altered as a result of the greater level of vitamins such as β-carotene in the forages fed to the cattle or because of changes in the fatty acid profile. Furthermore, grain-fed animals consume a greater energy (greater concentrate) diet, which allows excess energy to be used to develop intramuscular fat (marbling).

There were no differences in lean color measurements or pH between control and grass-fed strip steaks (Table 2). This is contradictory to previous studies, which indicated grass-fed beef is darker in color than conventionally fed beef (Bidner et al., 1976; Crouse and Seideman, 1984). Furthermore, earlier studies found grass-fed beef to have a greater pH (Ferguson, 2000) than feedlot finished beef (Wulf et al., 1997). The results of the current study may differ because all steaks had been frozen and thawed before quality evaluation.

Mineral and vitamin analyses were conducted on grass-fed beef samples, and the results are shown in Table 3. Williams et al. (1983) found that grass-fed steers, which were leaner than conventionally fed animals, had greater concentrations of Zn, Fe, P, Na, and K. Ground beef samples had significantly lesser levels of Mg, P, and K, and significantly greater levels of Na, Zn, and vitamin B_{12} than did strip steak samples (Table 3). The difference in mineral content may be due to the difference in fat content between the ground beef and strip steak samples (Table 4). Duckett et al. (1993) reported a slight increase in Fe and K content as fat content increased. Variations in mineral content of grass-fed beef were expected, because it is well documented that the level of many trace minerals in feeds is largely determined by the level in the soil where the feeds are grown or by other environmental factors (Preston, 2004).

The collection protocol stated that ground beef should be 85% lean and 15% fat. Although grass-fed beef producers did not always market 85% lean ground beef, the percentage of fat in grass-fed ground beef (12.8% fat) did not differ from control ground beef (14.2% fat) (Table 4). Furthermore, ground beef samples from grass-fed and control beef did not differ statistically in moisture, protein, or ash (Table 4).

Numerous studies have reported grass-fed beef to be leaner than conventionally raised beef (Melton et al., 1982; Marmer et al., 1984; French et al., 2000). The results of the current study were similar to those of past studies, which showed that control strip steaks had a greater fat content than grass-fed steaks (4.4 and 2.8%, respectively; $P = 0.001$). This fat difference was due to the greater intramuscular fat (marbling) content of the control steaks as compared with the grass-fed steaks (Table 2). Control steaks also had a decreased percentage of moisture than the grass-fed steaks ($P = 0.001$). Protein and ash contents of strip steaks were unaffected by treatments (Table 4). Previous studies have shown similar results, in which increased fat content resulted in a decreased moisture content of beef (Reagan et al., 1977; Duckett et al., 1993).

Although control strip steaks had a greater fat content than the grass-fed strip steaks, there was no difference in cholesterol content between the 2 treatments (Table 4). Moreover, grass-fed and control ground beef did not

Table 3. Vitamin and mineral content of raw strip steak and ground beef from grass-fed beef[1]

	Strip steaks[2] (n = 11)		Ground beef[2] (n = 11)		
Nutrient	Mean	SE	Mean	SE	*P*-value
Ca, mg	8.7	0.704	11.6	1.260	0.044
Cu, mg	0.070	0.004	0.065	0.002	0.407
Fe, mg	1.9	0.091	2.0	0.072	0.253
Mg, mg	23.1	0.282	18.5	0.347	0.001
Mn, mg	0.009	0.0004	0.010	0.0006	0.619
P, mg	211.9	1.94	174.8	3.2	0.001
K, mg	342.4	1.72	288.5	5.61	0.001
Se, μg	21.2	5.30	15.3	3.76	0.337
Na, mg	55.0	1.01	68.2	1.90	0.001
Zn, mg	3.6	0.141	4.6	0.127	0.001
Thiamin, mg	0.052	0.0019	0.050	0.0015	0.515
Vitamin B_{12}, μg	1.3	0.120	2.0	0.078	0.001
Total choline, mg	65.1	1.87	67.7	1.87	0.327

[1]Values are per 100 g of edible portion.

[2]Seven samples were composites of individual grass-fed animals from a single producer, and 4 samples were composites of animals from 2 different producers (8 producers total) that were identified to have similar genetics, have similar management practices, and be from the same region of the country. These composites were approved by the USDA Nutrient Data Laboratory.

differ in total cholesterol, but ground beef had significantly more cholesterol than did strip steaks (Table 4). Each steak was trimmed of all external fat; therefore, the only fat source was from intramuscular fat. Intramuscular fat has been found to contain less cholesterol than intermuscular fat (Sweeten et al., 1990). Likewise, Eichhorn et al. (1986) determined that adipose tissue contains about 2 times as much cholesterol as muscle tissue. Cholesterol data from the current study appear to support previous findings that total cholesterol was less for strip steaks than for ground beef samples ($P < 0.05$), because the only fat source in the strip steaks was from intramuscular fat.

The differences in fatty acid composition between grass-fed and control samples were similar for both ground beef and strip steaks. The concentrations of SFA were greater ($P = 0.001$) and those of MUFA were lesser ($P = 0.001$) for grass-fed ground beef than for control ground beef (Table 5). Likewise, grass-fed strip steaks had a greater amount of SFA ($P = 0.001$) and a decreased amount of MUFA ($P = 0.023$) than did control samples (Table 6). These results are similar to previous studies that found grass-fed beef to have more SFA and less MUFA than conventionally fed beef (Melton et al., 1982; Marmer et al., 1984); however, more recent studies have found grass-fed beef to have less SFA than grain-fed beef (French et al., 2000; Yang et al., 2002; Noci et al., 2005). Of the SFA, myristic and palmitic acids have the greatest impact on increasing serum cholesterol, but stearic acid has no effect on blood cholesterol (Ahrens et al., 1957; Hegsted et al., 1965; Keys et al., 1965). Data from the current study illustrate that the difference in SFA was primarily due to a greater concentration of stearic acid (18:0) in grass-fed ground beef compared with control ground beef ($P = 0.001$; Table 7). Moreover, concentrations of myristic and palmitic acids were not different between grass-fed and control ground beef (Table 7). The

Table 4. Means and SEM for percentages of moisture, fat, protein, and ash, and cholesterol content of raw strip steaks and ground beef from grain-fed (control) and grass-fed treatments

	Strip steaks					Ground beef				
	Control (n = 9)		Grass-fed[1] (n = 41)			Control (n = 9)		Grass-fed[2] (n = 42)		
Constituent	Mean	SE	Mean	SE	*P*-value	Mean	SE	Mean	SE	*P*-value
Moisture, %	71.6	0.25	73.5	0.19	0.001	65.9	0.64	67.1	0.47	0.772
Fat, %	4.4	0.41	2.8	0.17	0.001	14.7	0.80	12.8	0.58	0.800
Protein, %	23.2	0.15	23.1	0.12	0.613	19.2	0.17	19.4	0.15	0.511
Ash, %	0.8	0.09	0.7	0.06	0.655	0.4	0.13	0.8	0.09	0.093
Cholesterol,[3] mg/100 g	54.6	1.25	54.7	0.90	0.987	62.0	1.08	62.3	0.83	0.851

[1]Sample size represents 3 composite samples from 13 grass-fed producers and 1 composite sample from 2 grass-fed producers (n = 41).

[2]Sample size represents 3 samples from 13 grass-fed producers, 2 composite samples from a single producer, and 1 composite sample from another grass-fed producer (n = 42).

[3]Cholesterol sample size represents a single composite for each grass-fed producer (n = 14 for strip steaks and n = 15 for ground beef), and a single composite for each region (n = 3) in which the control samples were collected.

Table 5. Mean concentration of saturated, unsaturated, *trans*, n-3, and n-6 fatty acids in grass-fed and control raw ground beef as percentage of total fatty acids (g/100 g fat)

	Control		Grass-fed		
Fatty acid	Mean	SE	Mean	SE	*P*-value
SFA[1]	44.5	0.75	50.9	0.60	0.001
MUFA[2]	47.0	1.09	39.2	0.74	0.001
PUFA[3]	2.7	0.10	2.44	0.20	0.276
n-3	0.24	0.04	0.88	0.06	0.002
n-6	2.20	0.17	1.85	0.10	0.195
Total *trans*[4]	6.00	1.02	7.15	0.32	0.194
*c*9, *t*11 CLA	0.50	0.04	0.94	0.04	0.001
Total CLA	0.60	0.04	1.03	0.04	0.001
PUFA:SFA	0.059	0.004	0.050	0.004	0.904
n-6:n-3	9.60	1.44	2.45	0.39	0.001

[1]Total SFA = Σ 8:0, 10:0, 12:0, 14:0, 15:0, 16:0, 17:0, 18:0, and 20:0.
[2]Total MUFA = Σ 9*c* 14:1, 14*c* 15:1, 9*c* 16:1, 10*c* 17:1, 11*c* 20:1, 13*c* 22:1, 9*c* 18:1, 11*c* 18:1, 12*c* 18:1, 13*c* 18:1, 14*c* 18:1, and 15*c* 18:1 (where *c* = *cis*).
[3]Total PUFA = Σ 18:2, 18:3n-6, 18:4, 20:2n-6, 20:3, 20:4, 20:5n-3, 22:5n-3, and 22:6n-6.
[4]Total *trans* (*t*) fatty acids = Σ 5*t* 18:1; 6*t*, 8*t* 18:1; 9*t* 18:1; 10*t* 18:1; 11*t* 18:1; 12*t* 18:1; 13*t*, 14*t* 18:1; 16*t* 18:1; and *trans* 18:2.

ground beef results parallel those of the strip steaks because stearic acid (18:0) in the grass-fed strip steaks (17.0%) was greater ($P = 0.003$) than that in the control strip steaks (13.2%; Table 8). Grass-fed and control strip steak concentrations of palmitic acid did not differ, but concentrations of myristic acid were different ($P = 0.02$; Table 8).

Monounsaturated fatty acids have been shown to have positive health benefits (Groff and Gropper, 1999), and MUFA typically make up nearly half of beef fat. Oleic acid made up the greatest concentration of MUFA in both grass-fed and control ground beef and strip steaks (Tables 7 and 8). In both strip steaks and ground beef, the control treatment had a greater concentration of oleic acid than did the grass-fed treatment.

Grass-fed ground beef and strip steaks had a greater concentration of *trans*-vaccenic acid and total CLA ($P < 0.001$) than did control ground beef and strip steaks. The majority of the detectable CLA found in all beef samples was *cis*-9, *trans*-11. These results were similar to previous studies that also found the CLA content of grass-fed beef to be approximately 2 times greater than that of grain-fed beef (French et al., 2000; Yang et al., 2002; Noci et al., 2005). Moreover, *trans*-vaccenic acid made up the greatest concentration of total *trans* fats in grass-fed beef. Even so, CLA is the most widely stud-

Table 6. Mean concentration of saturated, unsaturated, *trans*, n-3, and n-6 fatty acids in grass-fed and control raw strip steaks as percentage of total fatty acids (g/100 g of fat)

	Control		Grass-fed		
Fatty acid	Mean	SE	Mean	SE	*P*-value
SFA[1]	45.1	0.50	48.8	0.53	0.002
MUFA[2]	46.2	0.90	42.5	0.60	0.023
PUFA[3]	2.77	0.25	3.41	0.19	0.129
n-3	0.19	0.01	1.07	0.11	0.002
n-6	2.58	0.25	2.30	0.13	1.000
Total *trans*[4]	6.04	0.99	5.30	0.25	0.294
9*c*, 11*t* CLA	0.38	0.03	0.66	0.07	0.093
Total CLA	0.48	0.04	0.85	0.04	0.001
PUFA:SFA	0.061	0.005	0.070	0.004	0.341
n-6:n-3	13.6	1.55	2.78	0.64	0.001

[1]Total SFA = Σ 8:0, 10:0, 12:0, 14:0, 15:0, 16:0, 17:0, 18:0, and 20:0.
[2]Total MUFA = Σ 9*c* 14:1, 14*c* 15:1, 9*c* 16:1, 10*c* 17:1, 11*c* 20:1, 13*c* 22:1, 9*c* 18:1, 11*c* 18:1, 12*c* 18:1, 13*c* 18:1, 14*c* 18:1, and 15*c* 18:1 (where *c* = *cis*).
[3]Total PUFA = Σ 18:2, 18:3n-6, 18:4, 20:2n-6, 20:3, 20:4, 20:5n-3, 22:5n-3, and 22:6n-6.
[4]Total *trans* (*t*) fatty acids = Σ 5*t* 18:1; 6*t*, 8*t* 18:1; 9*t* 18:1; 10*t* 18:1; 11*t* 18:1; 12*t* 18:1; 13*t*, 14*t* 18:1; 16*t* 18:1; and *trans* 18:2.

Table 7. Grass-fed and control raw ground beef fatty acid profile shown as percentage of total fatty acids (g/100 g of fat)

		Control		Grass-fed		
Fatty acid[1]	Common name	Mean	SE	Mean	SE	*P*-value
8:0	Caprylic	0.010	0.005	0.007	0.002	0.563
10:0	Capric	0.039	0.002	0.051	0.002	0.018
12:0	Lauric	0.077	0.003	0.088	0.003	0.173
14:0	Myristic	3.26	0.102	3.23	0.095	0.915
9*c* 14:1	Myristicoleic	0.886	0.039	0.660	0.049	0.068
15:0	Pentadecanoic	0.550	0.039	0.751	0.035	0.038
14*c* 15:1	Pentadecenoic	0.00	0.000	0.015	0.015	—
16:0	Palmitic	25.3	0.321	25.90	0.196	0.277
9*c* 16:1	Palmitoleic	3.91	0.177	3.21	0.116	0.021
17:0	Heptadecanoic	1.43	0.153	1.42	0.037	0.910
18:0	Stearic	13.7	0.670	19.2	0.653	0.001
5*t* 18:1		0.016	0.002	0.014	0.002	0.732
6*t*, 8*t* 18:1		0.333	0.043	0.215	0.017	0.012
9*t* 18:1	Elaidate	0.393	0.040	0.282	0.022	0.093
10*t* 18:1		2.69	1.11	0.752	0.054	0.001
11*t* 18:1	Vaccenic	1.14	0.195	4.14	0.247	0.001
12*t* 18:1		0.173	0.012	0.209	0.016	0.299
13*t*, 14*t* 18:1		0.434	0.030	0.601	0.031	0.039
16*t* 18:1		0.140	0.019	0.328	0.016	0.001
9*c* 18:1	Oleic	40.0	0.866	33.1	0.550	0.001
11*c* 18:1	*Cis*-vaccenic	1.77	0.072	1.16	0.038	0.002
12*c* 18:1		0.276	0.015	0.194	0.017	0.050
13*c* 18:1		0.576	0.041	0.302	0.020	0.001
14*c* 18:1		0.162	0.009	0.255	0.014	0.012
15*c* 18:1		0.241	0.0143	0.217	0.016	0.445
Trans 18:2		0.677	0.014	1.29	0.074	0.001
18:2	Linoleic	2.09	0.166	1.71	0.985	0.112
18:3n-3	Linolenic	0.207	0.022	0.676	0.049	0.001
18:4	Octadecatetraeonic	0.000	0.000	0.018	0.007	—
20:0	Arachidic	0.095	0.009	0.184	0.012	0.007
11*c* 20:1	Eicosenoic	0.205	0.010	0.139	0.007	0.001
20:2n-6	Eicosadienoic	0.025	0.014	0.012	0.005	0.368
20:3n-6	Eicosatrienoic	0.000	0.000	0.011	0.004	—
20:4n-6	Arachidonic	0.077	0.011	0.129	0.008	0.021
20:5n-3	Eicosapentaenoic	0.000	0.000	0.013	0.005	—
22:0	Behenic	0.000	0.000	0.035	0.004	—
22:5n-3	Docosapentaenoic	0.034	0.017	0.1581	0.012	0.002
22:6n-3	Docosahexaenoic	<1	—	<1	—	—

[1]*c* = *cis*; *t* = *trans*.

ied naturally occurring *trans*-fatty acid and has been shown to have positive health benefits (Bhattacharya et al., 2006; Tricon and Yaqoob, 2006). More specifically, CLA, in particular *cis*-9, *trans*-11, is believed to have several important physiological functions, including anticarcinogenic, antiatherogenic, immunomodulating, growth promotion, and lean body mass promotion (Tanaka, 2005).

Two forms of *trans*-fatty acids are found in foods, manufactured and naturally occurring. Manufactured *trans*-fatty acids are formed during the hydrogenation of unsaturated fatty acids such as those found in vegetable oils. Naturally occurring *trans*-fatty acids are found in any food product from ruminant animals. Naturally occurring and manufactured *trans*-fatty acids do not function equally because manufactured *trans*-fatty acids have been associated with a greater risk of coronary heart disease (Lopez-Garcia et al., 2005), whereas naturally occurring *trans* fats have been found to be beneficial to human health (Belury, 2002).

Kepler et al. (1966) determined that *Butyrivibrio fibrisolvens* transforms linoleic and linolenic acids into stearic acid in the rumen, which produces CLA as an intermediate. This is why ruminant fats are among the richest natural sources of CLA isomers, in particular the *cis*-9, *trans*-11 isomer (Chin et al., 1992; French et al., 2000). The concentration of CLA within ruminants can vary greatly (Mulvihill, 2001). Conjugated linoleic acid concentration in beef products can be altered because of variances in the diet of the animal, cut of meat, season, and genetics (Mulvihill, 2001).

There were no difference in total PUFA between the grass-fed and control treatments for both ground beef and strip steaks; however, grass-fed ground beef and strip steaks had a greater ($P = 0.002$) concentration of n-3 fatty acids than did the control samples (Tables 5

Table 8. Grass-fed and control raw strip steak fatty acid profile shown as a percentage of total fatty acids (g/100 g of fat)

		Control		Grass-fed		
Fatty acid[1]	Common name	Mean	SE	Mean	SE	*P*-value
10:0	Capric	0.058	0.002	0.04	0.008	0.301
12:0	Lauric	0.071	0.006	0.05	0.009	0.271
14:0	Myristic	3.45	0.090	2.84	0.117	0.020
9*c* 14:1	Myristicoleic	0.821	0.007	0.55	0.039	0.001
15:0	Pentadecanoic	0.487	0.033	0.54	0.021	0.233
16:0	Palmitic	26.3	0.573	26.9	0.337	0.465
9*c* 16:1	Palmitoleic	3.81	0.091	3.27	0.126	0.060
17:0	Heptadecanoic	1.36	0.101	1.23	0.038	0.219
18:0	Stearic	13.2	0.385	17.0	0.514	0.003
6*t*, 8*t* 18:1		0.382	0.047	0.15	0.0191	0.004
9*t* 18:1	Elaidate	0.355	0.016	0.27	0.017	0.054
10*t* 18:1		3.60	0.794	0.60	0.042	0.002
11*t* 18:1	Vaccenic	0.510	0.069	2.95	0.174	0.001
12*t* 18:1		0.191	0.024	0.17	0.019	0.489
13*t*, 14*t* 18:1		0.385	0.034	0.46	0.037	0.357
16*t* 18:1		0.101	0.007	0.24	0.015	0.001
9*c* 18:1	Oleic	38.6	0.814	36.5	0.444	0.044
11*c* 18:1	*Cis*-vaccenic	1.63	0.052	1.24	0.030	0.001
12*c* 18:1		0.318	0.049	0.18	0.023	0.021
13*c* 18:1		0.489	0.020	0.32	0.017	0.001
14*c* 18:1		0.109	0.003	0.19	0.014	0.011
15*c* 18:1		0.238	0.011	0.17	0.022	0.090
Trans 18:2		0.517	0.058	1.01	0.07	0.002
18:2	Linoleic	2.375	0.207	2.01	0.106	0.161
18:3n-3	Linolenic	0.128	0.008	0.71	0.064	0.001
20:0	Arachidic	0.077	0.004	0.132	0.009	0.024
11*c* 20:1	Eicosenoic	0.171	0.017	0.14	0.007	0.032
20:2n-6	Eicosadienoic	0.012	0.012	0.01	0.0048	0.757
20:4n-6	Arachidonic	0.193	0.033	0.31	0.044	0.222
22:5n-3	Docosapentaenoic	0.059	0.009	0.24	0.028	0.013
22:6n-3	Docosahexaenoic	<1	—	<1	—	—

[1]*c* = *cis*; *t* = *trans*.

and 6). This can be attributed to the greater amount of linolenic acid and its elongation products in the cattle diets. Furthermore, the n-6:n-3 ratio for control ground beef and strip steaks was greater ($P = 0.001$) than that of grass-fed ground beef and strip steaks.

Studies have established that the n-6 fatty acid linoleic acid, and the n-3 fatty acids linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid collectively protect against coronary heart disease (Wijendran and Hayes, 2004). Linoleic acid is the major dietary fatty acid regulating low-density lipoprotein cholesterol metabolism by downregulating low-density lipoprotein cholesterol production and enhancing its clearance (Wijendran and Hayes, 2004). By contrast, n-3 fatty acids, especially EPA and DHA, are potent antiarryhthmic agents (Wijendran and Hayes, 2004), but are typically found in very low levels in beef and other meat. Eicosapentaenoic acid and docosahexaenoic acid also improve vascular endothelial function and help lower blood pressure, platelet sensitivity, and serum triglycerides (Wijendran and Hayes, 2004). The distinct functions of these 2 families make the balance between dietary n-6 and n-3 fatty acids an important consideration influencing cardiovascular health (Wijendran and Hayes, 2004). Therefore, Wijendran and Hayes (2004) suggest that an adequate achievable intake for most healthy adults is approximately 6% linoleic acid, 0.75% linolenic acid, and 0.25% eicosapentaenoic acid and docosahexaenoic acid, which corresponds to an n-6:n-3 ratio of approximately 6:1. Even so, Wijendran and Hayes (2004) state the absolute mass of essential fatty acids consumed, rather than their n-6:n-3 ratio, should be the first consideration when contemplating lifelong dietary habits affecting cardiovascular benefit from their intake.

Some consumers have been motivated to buy grass-fed beef because sources show that it has a greater n-3 and CLA content than conventionally raised beef while also having less fat overall (Melton et al., 1982; Marmer et al., 1984; French et al., 2000). However, the effects on human health of the lipid differences between grass-fed and conventionally raised beef remain to be investigated. Although lean beef has consistently been shown to be beneficial in a cholesterol-lowering diet, it is still questionable whether grass-fed beef would have similar benefits.

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