Effects of winter stocker growth rate and finishing system on: III. Tissue proximate, fatty acid, vitamin, and cholesterol content

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Effects of winter stocker growth rate and finishing system on: III. Tissue proximate, fatty acid, vitamin, and cholesterol content[1]

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ABSTRACT: Angus-cross steers (n = 198; 270 kg of BW; 8 mo) were used in a 3-yr study to assess the effects of winter stocker growth rate and finishing system on LM proximate, fatty acid, cholesterol, vitamin, and mineral composition. During the winter months (December to April), steers were randomly allotted to 3 stocker growth rates: low (0.23 kg/d), medium (0.45 kg/d), or high (0.68 kg/d). At the completion of the stockering phase, steers were allotted randomly within each stocker growth rate to a high concentrate (CONC) or pasture (PAST) finishing system and finished to an equal time endpoint. Winter stocker growth rate did not alter ($P > 0.05$) proximate, cholesterol, or vitamin content of the LM. All interactions among winter stocker growth rate and finishing system were nonsignificant, indicating that supplementation systems during winter stocker period did not influence beef composition after finishing on PAST or CONC. Finishing steers on CONC decreased ($P < 0.001$) moisture content of the LM and increased ($P < 0.001$) lipid content of the LM. Protein, ash, and cholesterol content of the LM did not differ ($P > 0.05$) between finishing systems. α-Tocopherol and β-carotene content of the LM were 288 and 54% greater, respectively, for PAST-finished cattle than CONC. B-vitamins, thiamine and riboflavin, were also present in greater ($P = 0.001$) concentrations for PAST than CONC. Calcium, Mg, and K contents of the LM were greater ($P < 0.05$) for PAST than CONC. Total fatty acid content of the LM was 49% less for PAST than CONC. Myristoleic, palmitoleic, and oleic acid concentrations were all less ($P = 0.001$) for PAST than CONC. *Trans*-10 octadecenoic acid percentage in LM was 97% greater ($P = 0.001$) for CONC than PAST; conversely, *trans*-11 vaccenic acid percentage in the LM was 90% greater ($P = 0.001$) for PAST than CONC. Conjugated linoleic acid, *cis*-9, *trans*-11 isomer, percentage was greater ($P = 0.001$) by 117% for PAST than CONC. Linoleic acid (C18:2) concentration did not differ ($P > 0.05$) among PAST and CONC. Concentrations of all n-3 fatty acids (linolenic acid, eicosapentaenoic, docosapentaenoic, docosahexaenoic) were greater ($P = 0.01$) for PAST than CONC. Total n-6 PUFA percentages were unchanged ($P > 0.05$) among finishing systems. The ratio of n-6 to n-3 fatty acids was 4.84 for CONC and 1.65 for PAST. Beef from CONC finished has a greater total, saturated, and monounsaturated fat content; in contrast, beef from PAST finished has less total, saturated, and monounsaturated fat content with greater contents of n-3 fatty acids and a decreased n-6 to n-3 ratio. Beef from PAST finished also has greater contents of B-vitamins and antioxidants (vitamin E and β-carotene).

Key words: beef, fatty acid, forage, proximate

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INTRODUCTION

Consumer markets for natural, forage-finished beef products are expanding in the United States (Roosevelt, 2006). As a result of this demand, some beef producers are starting to finish cattle on forages and direct market this grass-fed beef to consumers. Agricultural Marketing Service has established a voluntary standard for a grass (forage)-fed marketing claim for ruminant livestock (USDA-AMS, 2007). The grass (forage)-fed claim and standard states that grass and forage shall be the feed source consumed for the lifetime of the ruminant animal, with the exception of milk consumed before weaning. The diet shall be derived solely from forage consisting of grass (annual and perennial), forbs (e.g., legumes, *Brassica*), and browse, or cereal grain crops in vegetative state. Animals cannot be fed grain or grain-by-products and must have continuous access to pasture during the growing season. Hay, haylage, baleage, silage, crop residue without grain, and other

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roughage sources may also be included as acceptable feed sources. Producers can now request a grass-fed claim be verified by USDA through an audit of the production process.

Forage fatty acid content is variable among species, variety, harvest time, and growing season (Dewhurst et al., 2001; Clapham et al., 2005). These differences in forage fatty acid content influence meat and milk fatty acids produced in grazing animals (Dewhurst et al., 2003). Several studies (Marmer et al., 1984; Mitchell et al., 1991; Mandell et al., 1998; French et al., 2000; Realini et al., 2004b; Noci et al., 2005) have compared the fatty acid composition of grass-fed with grain-fed beef; however, several of these studies were conducted outside of the United States and most were conducted for 1 yr with limited sample size. Leheska et al. (2008) compared nutrient composition of conventional with grass-fed beef; however, the comparison was not an in-trial comparison because the grass-fed beef was obtained through on-line Web sites and grain-fed beef obtained from an on-campus study. Therefore, multiple-year, in-trial comparisons are needed to directly assess compositional differences due to finishing system. In addition, limited information is available on the effects of supplementation or growth rate during stockering and its effect on subsequent finished beef nutrient composition. The objective of this research was to evaluate the effect of stocker growth rate and finishing system on LM proximate, fatty acid, vitamin, and mineral content, and subcutaneous (**s.c.**) fatty acid composition.

MATERIALS AND METHODS

The experimental procedures were reviewed and approved by the respective institutional animal care and use committees.

Angus-cross steers (n = 198; in BW = 289 ± 3.8 kg) were used in a 3-yr study to assess changes in rib composition, color, and palatability with different winter stocker growth rates and finishing systems. The steers were held during the winter months on a drylot from early December through mid-April. In each year, steers were randomly allotted to 3 stocker growth rates: low (0.23 kg/d), medium (0.45 kg/d), or high (0.68 kg/d). Winter stockering diets consisted of timothy hay, soybean meal, soybean hull, and 6 Ca:1 P mineral mix (SSC-377808 Livestock Mineral, Southern States Coop., Richmond, VA). At the completion of the stockering phase, steers were randomly allotted within each stocker growth rate to a corn-silage concentrate (**CONC**) or pasture (**PAST**) finishing system. The composition of the supplements and finishing diet is available in Neel et al. (2007). No anabolic implants or ionophores were used in this experiment. Steers on the PAST treatment grazed mixed pasture, which consisted of a mix of bluegrass (*Poa pratensis* L.), orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca* L.), and white clover (*Trifolium repens* L.) for majority of the time and hay meadow regrowth and triticale (*Triticale hexaploide* L.)/Italian ryegrass (*Lolium multiflorum* Lam.) for short periods of time. All steers regardless of finishing treatment were finished to an equal time endpoint (yr 1 = 152 d; yr 2 = 174 d; yr 3 = 150 d; avg HCW = 326.8 kg for CONC and 248.9 kg for PAST) to minimize confounding due to animal age. Additional information on animal performance, carcass characteristics, rib composition, and tenderness is available in Duckett et al. (2007) and Neel et al. (2007).

At the end of the finishing phase, steers were transported to a commercial packing plant for slaughter. At 24 h postmortem, carcasses were graded by trained personnel, and the ribs (IMPS 107) from the left side of each carcass were identified, removed, vacuum-packed, and shipped via refrigerated semi-truck to the University of Georgia Meat Science Technology Center (Athens). Upon arrival at the meat laboratory, ribs were maintained at 4°C until 14 d of postmortem aging was complete. After 14 d of postmortem aging, the ribs were removed from vacuum-packaged bags and allowed to bloom for at least 30 min. Steaks (2.54 cm thick) were removed from the posterior end (12th rib) of each rib for proximate, cholesterol, and fatty acid composition. All external fat and connective tissue were removed from the LM. Subcutaneous fat samples were also removed from the 12th-rib area for fatty acid composition. The s.c. adipose and LM samples from each carcass were pulverized in liquid nitrogen and stored at −20°C.

Proximate Composition

Duplicate samples of LM were analyzed for nitrogen content by the combustion method using a Leco FP-2000 N analyzer (Leco Corp., St. Joseph, MI) and multiplied by 6.25 to determine CP content. Moisture content was determined by weight loss after drying at 100°C for 24 h. Total ash content was determined by ashing at 600°C for 8 h (AOAC, 2000). Total lipids were extracted in duplicate from LM and s.c. samples according to the procedures of Folch et al. (1957). Cholesterol content of LM was determined according to Du and Ahn (2002) and quantified by incorporating an internal standard, stigmasterol, into each sample. Fat soluble vitamin (α-tocopherol and β-carotene) content of the LM was determined according to the method of Lee et al. (2005) with 95% recovery rate for both vitamins. Briefly, LM samples were saponified in sodium hydroxide, extracted with isooctane, and analyzed by HPLC (Shimadzu, Columbia, MD) with SupelcoSIL (Supelco, St. Louis, MO) column and UV/visible detector. Thiamine and riboflavin concentrations were determined according to the method of Barna and Dworschak (1994). Samples of LM were homogenized in 0.01 *M* HCl and autoclaved for 30 min. An enzyme suspension containing taka-diastase, clara-diastase, and papain were added to the autoclaved samples after pH adjustment to 4.5 and incubated at 37°C for 16 to 18 h to release bound enzymes. Samples were filtered, pH adjusted to 6.5, cleaned up using Nucleosil C_{18} cartridg-

es and analyzed by HPLC (Shimadzu) using a Supelco C18 column and UV detector.

Fatty Acid Composition

Subcutaneous and LM lipid extracts containing approximately 4 mg of total lipids were transmethylated according to the method of Park and Goins (1994). Fatty acid methyl esters (**FAME**) were analyzed using a HP6850 (Hewlett-Packard, San Fernando, CA) gas chromatograph equipped with a HP7673A (Hewlett-Packard) automatic sampler. Separations were accomplished using a 100-m SP2560 (Supelco, Bellefonte, PA) capillary column (0.25 mm i.d. and 0.20-μm film thickness). Column oven temperature increased from 150 to 160°C at 1°C per min, from 160 to 167°C at 0.2°C per min, from 167 to 225°C at 1.5°C per min, and then held at 225°C for 16 min. The injector and detector were maintained at 250°C. Sample injection volume was 1 μL. Hydrogen was the carrier gas at a flow rate of 1 mL per min. Individual fatty acids were identified by comparison of retention times with standards (Sigma, St. Louis, MO; Supelco; Matreya, Pleasant Gap, PA). Fatty acids were quantified by incorporating an internal standard, methyl heptacosanoic (C27:0) acid, into each sample during methylation and expressed as a percentage of total fatty acids.

Statistical Analyses

Data were analyzed in a completely randomized design using GLM procedures (SAS Inst. Inc., Cary, NC) with stocker growth rate, finishing system, and 2-way interaction as fixed effects and year as a random effect. The experimental unit was steer for all comparisons. Least square means were generated and separated using the PDIFF option of SAS. Significance was determined at $P \leq 0.05$, whereas differences of $P > 0.05$ to $P \leq 0.10$ were considered as trends.

RESULTS AND DISCUSSION

The effect of winter stocker growth rate and finishing system on LM proximate composition is shown in Table 1. Winter stocker growth rate did not alter ($P > 0.05$) moisture, protein, lipid, ash, or cholesterol content of the LM. However, there was a trend ($P = 0.07$) for LM lipid content to increase with growth rate during the stocker period. These data agree with carcass quality grade data in which stocker growth rate increased quality grade in concentrate finished steers (Neel et al., 2007). Finishing steers on CONC had decreased ($P < 0.001$) moisture content of the LM and increased ($P < 0.001$) lipid content of the LM. Pasture-finished steers had 42.5% less total lipid content of the LM compared with CONC-finished cattle. Protein, ash, and cholesterol content of the LM did not differ ($P > 0.05$) between finishing systems. Similarly, Leheska et al. (2008) reported a 36% reduction in total lipid content of grass-fed vs. conventional beef and no difference in protein, ash, or cholesterol content. Williams et al. (1983) found less total fat content, greater CP, moisture and ash content, and similar cholesterol concentrations of soft tissues from grass-fed compared with grain-fed beef. Many grass-fed beef producers report reduced cholesterol content for grass-fed beef; however, cholesterol is present in muscle cell membranes and intramuscular fat. Rhee et al. (1982) reported cholesterol contents of beef from all marbling scores and only found significant differences among the extremes in marbling score (moderately abundant vs. practically devoid) for cholesterol content. Sweeten et al. (1990) reported that marbling contributes little to total cholesterol content of beef muscle.

α-Tocopherol and β-carotene content of the LM were 288 and 54% greater, respectively, for PAST than CONC. Yang et al. (2002a) also reported greater fat-soluble vitamin contents for grass-fed beef; however, they reported decreased α-tocopherol and β-carotene content for pasture-fed cattle in their study conducted in Australia compared with this study. Similarly, Warren et al. (2008) found greater muscle tocopherol content for grass-silage-finished compared with concentrate-finished beef. Liu et al. (1995) suggested that the threshold level of muscle α-tocopherol is 3.5 μg/g for extended color and lipid stability. Grass-fed beef contained 7.73 μg/g α-tocopherol compared with 1.99 μg/g for grain-fed beef. These α-tocopherol concentrations for grass-fed and grain-fed beef would suggest differences in shelf-life of the products, with grass-fed beef containing 121% greater and grain-fed containing 43% less content than the threshold level for increased color and lipid stability. Few reports of shelf-life studies comparing grass-fed and grain-fed beef have been reported. Realini et al. (2004a) found that ground beef from grass-fed sources did have greater lipid stability and less thiobarbituric acid reactive substances compared with grain-fed during 8 d of display. Realini et al. (2004a) also found that antioxidant addition (vitamin C) to ground beef samples improved color and lipid stability in grain-fed beef only and had no effect on grass-fed ground beef. Similarly, Yang et al. (2002a,b) also reported that vitamin E supplementation to pasture-fed cattle did not further increase LM α-tocopherol concentrations or extend shelf-life of the product. The concentrations of α-tocopherol in this study would be at saturation levels according to Arnold et al. (1993). Warren et al. (2008) reported decreased lipid oxidation in steaks from grass-silage compared with concentrate-finished beef associated with the greater tocopherol concentrations and less n-6 fatty acid content.

B-vitamins, thiamine and riboflavin, were also present in greater ($P = 0.001$) concentrations for PAST than CONC. Winter stocker growth rate did not alter ($P > 0.05$) fat-soluble vitamin or thiamine concentrations. Riboflavin content of the LM was increased ($P = 0.02$) with increasing winter stocker growth rates. Calcium, Mg, and K contents of the LM were greater

Table 1. Effect of winter stocker growth rate and finishing system on LM proximate analyses and vitamin and mineral content

	Stocker growth rate[1] (S)			Finishing system[2] (F)			*P*-value		
Item	Low	Medium	High	CONC	PAST	SE	S	F	S × F
No. of observations	67	66	65	103	95				
Proximate composition, g/100 g									
Moisture	73.71	73.56	73.30	72.44	74.60	1.21	0.20	0.001	0.15
Protein	21.84	21.83	21.73	21.70	21.90	0.68	0.71	0.11	0.62
Lipid	3.02[d]	3.09[d]	3.51[c]	4.07	2.34	1.20	0.07	0.001	0.10
Ash	1.15	1.16	1.15	1.16	1.15	0.09	0.78	0.45	0.44
Cholesterol, mg/100 g	57.01	56.89	56.44	56.29	57.27	4.48	0.82	0.26	0.47
Fat-soluble vitamins, μg/100 g									
α-Tocopherol	494.14	469.13	495.71	199.23	773.43	16.28	0.65	0.001	0.33
β-Carotene	40.29	35.70	32.64	28.53	43.88	2.86	0.27	0.001	0.79
B vitamin, μg/100 g									
Riboflavin	325.82[b]	337.34[ab]	359.07[a]	224.15	457.34	56.58	0.02	0.001	0.10
Thiamine	49.16	45.66	47.14	23.99	70.65	14.49	0.52	0.001	0.54
Mineral, mg/100 g									
Calcium	6.42	6.13	6.21	5.35	7.17	2.23	0.78	0.001	0.40
Magnesium	20.88	20.87	20.97	20.74	21.08	0.95	0.86	0.02	0.11
Sodium	168.30[ab]	160.84[b]	176.89[a]	165.16	172.20	30.06	0.02	0.13	0.75
Potassium	304.42[a]	309.86[a]	285.25[b]	293.12	306.56	41.30	0.01	0.04	0.10
Zinc	3.88[b]	4.12[a]	4.16[a]	4.01	4.10	0.65	0.05	0.39	0.80
Iron	1.53[b]	1.57[b]	1.88[a]	1.62	1.70	0.75	0.03	0.48	0.89

[a,b]Means with uncommon superscripts differ ($P < 0.05$).
[c,d]Means with uncommon superscripts differ ($P \leq 0.10$).
[1]Stocker growth rate: low = 0.23 kg/d, medium = 0.45 kg/d, and high = 0.68 kg/d.
[2]Finishing system: CONC = high concentrate diet or PAST = pasture only.

($P < 0.05$) for PAST than CONC. Other minerals (Na, Zn, and Fe) were unchanged ($P > 0.05$) with finishing system. Winter stocker growth rate altered ($P < 0.05$) Na, K, Zn, and Fe contents in the LM. Increasing winter stocker growth rate resulted in greater ($P < 0.05$) contents of Na, Zn, and Fe in the LM, whereas K contents were decreased ($P < 0.05$) with increasing stocker growth rate. Leheska et al. (2008) reported similar concentrations of thiamine and minerals in grass-fed strip steaks. Duckett et al. (1993) also reported similar mineral concentrations in LM of steers stockered on pasture and then fed concentrates from 0 to 196 d on feed with Fe, Mg, and K concentrations increasing with time on feed. Williams et al. (1983) reported greater concentrations of Zn, P, Mg, and K in grass-fed beef compared with grain-fed beef. Mineral content of LM of grass-fed beef would be highly dependent on forage type and quality during the grazing period.

The effect of winter stocker growth rate and finishing system on LM fatty acid composition is shown in Table 2. Winter stocker growth rate did not alter ($P > 0.05$) the percentage of myristic (C14:0), myristoleic (C14:1), pentadecyclic (C15:0), palmitoleic (C16:1), margaric (C17:0), *trans* octadecenoic (C18:1 *trans*-10 or *trans*-11), *cis* octadecenoic (C18:1 c11), linoleic, linolenic, arachidonic, eicosapentaenoic (**EPA**), docosapentaenoic (**DPA**), or unidentified fatty acids. Palmitic (C16:0) acid concentration was greater ($P = 0.02$) for high compared with low or medium growth rate. Oleic (C18:1 *cis*-9) acid concentration was greater ($P = 0.03$) for medium and high, compared with low. Conversely, docosahexaenoic (**DHA**) concentration was less ($P = 0.01$) for medium and high compared with low. Monounsaturated fatty acid concentration was greater ($P = 0.02$) for medium and high than low due to the increases in oleic acid concentration. Waldmann et al. (1968) and Link et al. (1970) reported increased palmitic acid and oleic acid concentrations in LM associated with animal growth rate. No interactions among stocker growth rate and finishing system were observed, indicating that finished beef composition, regardless of finishing system, was not influenced by stocker growth rate. Based upon our beef production system, we would estimate that these PAST-finished steers received approximately 98, 95, and 91% for low, medium, and high, respectively, of their lifetime intake from pasture during the growing season or hay during the winter stocker period. The steers received soybean meal and soybean hulls in varying amounts (8 to 41% of diet DM) depending on stocker growth rate treatment during the winter stocker period. The lack of an effect of stocker growth rate and any interactions with finishing system on *trans*-11 vaccenic acid, CLA, n-6, n-3, and n-6 to n-3 ratio would indicate that feeding steers varying levels of soybean hulls and soybean meal during the winter stocker period did not influence beef composition after finishing on forages for 150 d before slaughter.

Finishing system altered fatty acid composition of the LM and total fatty acid content. Total fatty acid content of the LM was 49% less for PAST than CONC. Concentrations of myristic and palmitic acids were less ($P < 0.01$) for PAST than CONC. Stearic (C18:0) acid

Table 2. Effect of winter stocker growth rate and finishing system on LM fatty acid composition

	Stocker growth rate[1] (S)			Finishing system[2] (F)			*P*-value		
Item	Low	Medium	High	CONC	PAST	SE	S	F	S × F
No. of observations	67	66	65	103	95				
Total fatty acids, g/100 g	2.63	2.74	2.91	3.65	1.87	1.02	0.48	0.001	0.79
Fatty acid, weight %									
C14:0, %	2.69	2.56	2.63	2.79	2.46	0.36	0.44	0.003	0.88
C14:1, %	0.47	0.51	0.49	0.60	0.38	0.14	0.29	0.001	0.69
C15:0, %	0.53	0.52	0.52	0.45	0.59	0.12	0.98	0.001	0.65
C16:0, %	25.34[b]	25.25[b]	25.93[a]	26.68	24.34	1.42	0.02	0.001	0.07
C16:1, %	3.00	3.08	3.19	3.46	2.72	0.38	0.16	0.001	0.99
C17:0, %	1.26	1.22	1.23	1.34	1.14	0.28	0.95	0.105	0.88
C18:0, %	16.17	15.38	15.56	13.98	17.44	1.59	0.10	0.001	0.17
C18:1 *trans*-10, %	0.97	0.69	0.66	1.51	0.04	0.56	0.42	0.001	0.43
C18:1 *trans*-11, %	1.85	1.79	1.87	0.32	3.34	0.57	0.73	0.001	0.20
C18:1 *cis*-9, %	33.72[b]	34.66[a]	34.82[a]	37.93	30.87	2.11	0.03	0.001	0.88
C18:1 *cis*-11, %	1.23	1.29	1.25	1.44	1.08	0.13	0.49	0.001	0.94
C18:2n-6, %	2.85	2.91	2.82	2.97	2.75	0.66	0.88	0.131	0.18
C18:2 *cis*-9, *trans*-11, %	0.56	0.59	0.57	0.36	0.78	0.13	0.70	0.001	0.56
C18:2 *cis*-11, *trans*-13, %	0.01	0.01	0.01	0.01	0.01	0.01	0.28	0.003	0.87
C18:2 *trans*-10, *cis*-12, %	0.02	0.02	0.02	0.01	0.02	0.01	0.98	0.24	0.99
C18:2 *cis*, *cis*, %	0.04	0.04	0.04	0.02	0.06	0.02	0.90	0.003	0.84
C18:2 *trans*, *trans*, %	0.08	0.09	0.09	0.06	0.11	0.02	0.84	0.001	0.48
C18:3n-3, %	0.72	0.76	0.71	0.37	1.08	0.18	0.47	0.001	0.56
C20:4n-6, %	0.90	0.91	0.83	0.74	1.02	0.32	0.52	0.001	0.38
C20:5n-3, %	0.31	0.30	0.24	0.11	0.46	0.13	0.23	0.001	0.40
C22:5n-3, %	0.51	0.50	0.42	0.26	0.70	0.16	0.23	0.001	0.50
C22:6n-3, %	0.07[a]	0.06[b]	0.05[b]	0.04	0.08	0.03	0.01	0.001	0.27
Unidentified, %	6.54	6.71	5.88	4.35	8.40	2.47	0.13	0.001	0.56
SFA, %	44.21	43.19	44.12	43.44	44.24	2.43	0.10	0.06	0.32
Odd-chain, %	1.79	1.74	1.75	1.79	1.74	0.39	0.96	0.74	0.87
MUFA, %	37.19[b]	38.26[a]	38.50[a]	41.99	33.97	2.27	0.02	0.001	0.89
n-6 PUFA,%	3.75	3.82	3.65	3.71	3.77	0.95	0.74	0.74	0.16
n-3 PUFA, %	1.61	1.62	1.42	0.79	2.32	0.46	0.25	0.001	0.42
n-6:n-3 ratio	3.22	3.21	3.31	4.84	1.65	0.61	0.96	0.001	0.86

[a,b]Means with uncommon superscripts differ ($P < 0.05$).
[1]Stocker growth rate: low = 0.23 kg/d, medium = 0.45 kg/d, and high = 0.68 kg/d.
[2]Finishing system: CONC = high concentrate diet or PAST = pasture only.

concentration was greater ($P = 0.001$) for PAST than CONC. Overall SFA concentration did not differ ($P = 0.06$) between finishing systems. Pentadecylic (C15:0) acid concentration was greater ($P < 0.05$) for PAST than CONC. Margaric (C17:0) acid and total odd chain fatty acid concentrations were unchanged ($P > 0.05$) between finishing systems. Mitchell et al. (1991) also reported no change in total SFA content of LM from grain- or forage-finished animals.

Myristoleic, palmitoleic, and oleic acid concentrations were all less ($P = 0.001$) for PAST then CONC. Oleic acid concentration and total MUFA of the LM were 19% less ($P = 0.001$) for PAST than CONC. Others (Mitchell et al., 1991; Mandell et al., 1998; Faucitano et al., 2008) also showed greater MUFA and oleic acid concentrations in grain-fed vs. grass-fed beef. Duckett et al. (1993) reported a linear increase in MUFA and oleic acid concentration during finishing on a high grain diet from 0 to 196 d on feed. Additional research has shown that stearoyl-CoA desaturase mRNA expression is 46-fold greater in s.c. adipose of steers finished high concentrate diets compared with pasture-finished (Duckett et al., 2008). These results indicate that grain-finishing enhances oleic acid concentration due to upregulation of stearoyl-CoA desaturase, the enzyme responsible for the desaturation of stearic to oleic acid.

Trans-10 octadecenoic acid percentage in LM was 97% greater ($P = 0.001$) for CONC than PAST. Conversely, *trans*-11 vaccenic acid percentage in the LM was 90% greater ($P = 0.001$) for PAST than CONC. Duckett et al. (2002) and Sackmann et al. (2003) found that high concentrate diets favor the *trans*-10 pathway of biohydrogenation. Faucitano et al. (2008) also reported that feeding high concentrate diets resulted in greater *trans*-10 C18:1 in the LM compared with forage-finished. Conjugated linoleic acid, *cis*-9 *trans*-11 isomer, was greater ($P = 0.001$) by 117% for PAST than CONC. Others (French et al., 2000; Realini et al., 2004b; Faucitano et al., 2008) have reported similar increases in *cis*-9, *trans*-11 CLA percentages for forage-finished beef compared with concentrate-finished. Distribution of CLA *cis*-9, *trans*-11 concentration in the LM is presented in Figure 1. Conjugated linoleic acid, *cis*-9, *trans*-11 isomer, percentage ranged from 0.16 to 0.56% and 0.46 to 1.18% of total fatty acids for CONC and PAST, respectively. These results show that there

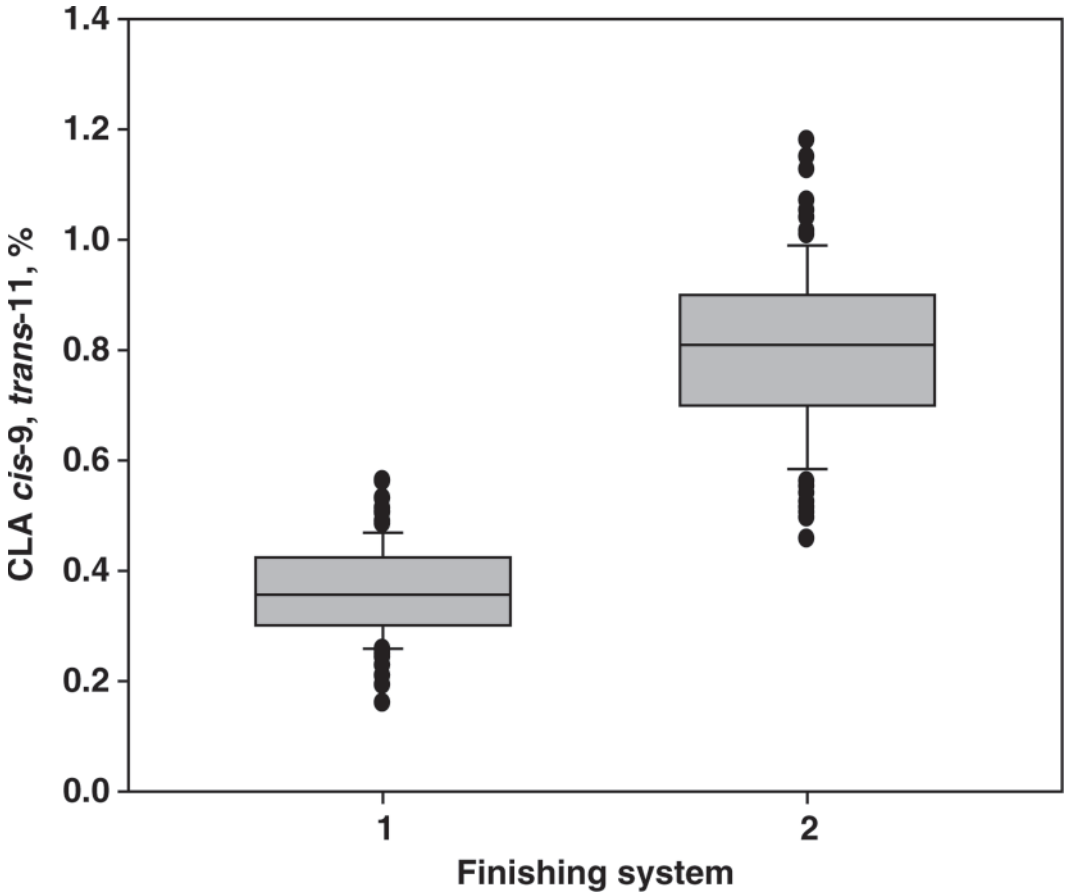

Figure 1. Box plot of CLA *cis*-9 *trans*-11 percentage in LM by finishing system (1 = high concentrate diet; 2 = pasture only).

is a large amount of variation in the CLA *cis*-9 *trans*-11 isomer percentage within finishing systems and a region of overlap among the finishing systems. Kelsey et al. (2003) also reported large variation in *cis*-9 *trans*-11 CLA content in milk fat of cows consuming the same diet. These authors attributed the genetic variation in individual cows to the rumen output of *trans*-11 vaccenic acid and *cis*-9, *trans*-11 CLA, and tissue stearoyl-CoA desaturase amount and activity in the tissues. Other isomers of CLA (*cis*-11, *trans*-13; *cis*, *cis*; *trans*, *trans*) were also greater ($P = 0.001$) in PAST than CONC. *Trans*-10, *cis*-12 isomer of CLA did not differ ($P > 0.05$) between PAST and CONC finished.

Linoleic acid (C18:2) concentration did not differ ($P > 0.05$) among PAST and CONC. Others (Schroeder et al., 1980; Mitchell et al., 1991; Mandell et al., 1998) have also reported that linoleic acid is not affected by finishing system. Arachidonic acid (C20:4) percentage was greater ($P = 0.001$) for PAST than CONC. Concentrations of all n-3 fatty acids (linolenic acid, EPA, DPA, DHA) were greater ($P = 0.01$) for PAST than CONC. Duckett et al. (1993) and Mandell et al. (1998) have shown that grain feeding will reduce linolenic acid concentrations in LM. Total n-6 PUFA percentages were unchanged ($P > 0.05$) between finishing systems. Total n-3 PUFA was 194% greater ($P = 0.01$) for PAST than CONC due to increases in all individual n-3 fatty acids in PAST. Similarly, French et al. (2000) found increased linolenic and total n-3 fatty acid and no difference in linoleic and total n-6 fatty acid concentrations in LM of steers fed grass only vs. various supplementation systems to silage- or hay-based diets. The ratio of n-6 to n-3 fatty acids was 4.84 for CONC and 1.65 for PAST. Health professionals recommend the consumption of diets with an n-6 to n-3 ratio of 4:1 or less (Simopoulos, 2008). Many others have reported similar reductions in n-6 to n-3 ratios for grass-fed beef compared with concentrate-finished (Wood and Enser, 1997; French et al., 2000; Realini et al., 2004b). Noci et al. (2005) found a linear decrease in n-6 to n-3 ratios with increasing duration of grazing days. The n-6 to n-3 values reported here for 150 to 174 d of pasture finishing are similar to those reported in Noci et al. (2005) for 99 to 158 d of pasture finishing. Figure 2 shows the distribution of the n-6 to n-3 ratio by finishing system. The distribution of n-6 to n-3 ratio levels in PAST is less than CONC, and there is separation between the treatments at a ratio of 2.44. Thus, the ratio of n-6 to n-3 fatty acids in the LM is the single best measure to potentially verify finishing system in beef samples.

Stocker growth rate did not alter ($P > 0.05$) total fatty acid content of the s.c. adipose tissue (Table 3). Myristoleic and palmitoleic acid concentrations were greater ($P < 0.05$) for high than low with medium being intermediate. Palmitic acid and DPA concentrations were greater ($P < 0.05$) for high than low or medium.

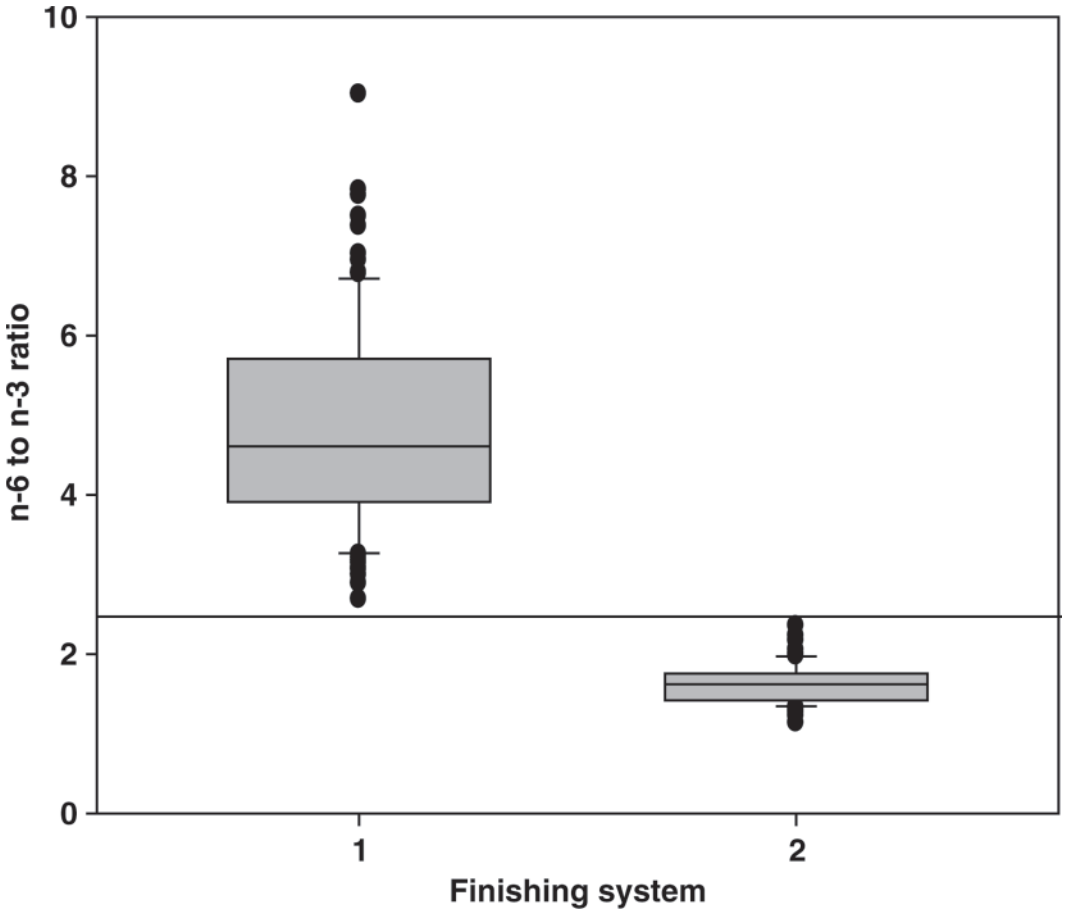

Figure 2. Box plot of n-6 to n-3 ratio in LM by finishing system (1 = high concentrate diet; 2 = pasture only). Line separating the 2 finishing systems is at 2.44 ratio of n-6 to n-3 fatty acids.

Stearic acid concentration was greater ($P = 0.04$) for low than medium or high. Concentrations of other fatty acids (myrisitic, pentadecyclic, margaric, *trans*- or *cis*-octadecenoic, linoleic, CLA isomers, arachidonic, EPA, or DPA acids) were unaffected ($P > 0.05$) by stocker growth rate. No interactions among stocker growth rate and finishing system were observed.

Total fatty acid content of the s.c. adipose tissue was greater ($P = 0.001$) for CONC than PAST (Table 3). Similarly, Pavan et al. (2007) have reported less total fatty acid contents of adipose tissues in PAST compared with energy (corn grain or corn oil plus soybean hulls) supplemented or high concentrate finished, due to limited hypertrophy of the adipocyte with less energy diets. Myristic, palmitic, and stearic acid percentages were greater ($P < 0.001$) for PAST than CONC. Total SFA concentration was also greater ($P = 0.001$) for PAST than CONC. These results for s.c. adipose tissue are in contrast to LM, where stearic acid was the only SFA present in greater amounts for PAST than CONC. Concentrations of pentadecyclic acid were greater ($P = 0.001$) for PAST than CONC. Margaric acid and total odd chain fatty acid concentrations were unchanged ($P > 0.05$) with finishing system.

Myristoleic and oleic acid percentages in s.c. adipose were greater ($P = 0.001$) for CONC than PAST; however, palmitoleic acid percentage was unchanged ($P > 0.05$) by finishing system. Total MUFA concentration was greater by 26% for CONC compared with PAST. These results are similar to those reported for LM and results of other researchers (Mitchell et al., 1991; Duckett et al., 1993; Mandell et al., 1998) who also observed greater MUFA concentrations in grain-fed animals. Similar to LM, *trans*-10 octadecenoic acid concentration was greater ($P = 0.001$) for CONC than PAST, whereas *trans*-11 vaccenic acid concentrations were greater ($P = 0.001$) for PAST than CONC. Because *trans*-11 vaccenic acid can be converted to *cis*-9 *trans*-11 isomer of CLA, it is considered a beneficial fatty acid. *Trans*-10 octadecenoic predominates in tissues of animals fed high concentrate diets.

Linoleic acid, arachidonic acid, and total n-6 fatty acid concentrations in s.c. adipose were less ($P = 0.001$) for PAST than CONC. Linolenic acid, EPA, DPA, and total n-3 fatty acid concentrations were greater ($P = 0.001$) for PAST than CONC. Concentrations of DHA were unchanged ($P > 0.05$) with finishing system. The ratio of n-6 to n-3 fatty acids was less ($P = 0.001$), more desirable from a human health standpoint, for PAST than CONC.

Due to the changes in the total fatty acid content of the LM, it is important to evaluate these changes in

Table 3. Effect of winter stocker growth rate and finishing system on subcutaneous fatty acid composition

	Stocker growth rate[1] (S)			Finishing system[2] (F)			*P*-value		
Item	Low	Medium	High	CONC	PAST	SE	S	F	S × F
No. of observations	67	66	65	103	95				
Total fatty acids, g/100 g	66.79	65.56	65.82	68.58	63.53	6.72	0.50	0.001	0.39
Fatty acid, weight %									
C14:0, %	3.26	3.28	3.47	3.11	3.56	0.48	0.09	0.001	0.71
C14:1, %	0.82[b]	0.93[ab]	0.99[a]	1.02	0.81	0.28	0.03	0.001	0.73
C15:0, %	0.66	0.69	0.72	0.53	0.86	0.12	0.37	0.001	0.66
C16:0, %	25.48	25.68	26.35	25.65	26.02	1.36	0.004	0.05	0.10
C16:1, %	3.82[b]	4.18[ab]	4.44[a]	4.28	4.01	0.76	0.02	0.11	0.94
C17:0, %	1.42	1.34	1.35	1.41	1.33	0.27	0.82	0.43	0.83
C18:0, %	15.89[a]	14.76[b]	14.48[b]	12.70	17.39	2.51	0.04	0.001	0.99
C18:1 *trans*-10, %	1.58	1.17	1.07	2.37	0.18	0.78	0.38	0.001	0.51
C18:1 *trans*-11, %	2.85	2.71	2.84	0.42	5.18	1.09	0.76	0.001	0.21
C18:1 *cis*-9, %	36.08	36.89	35.76	40.78	31.70	3.12	0.21	0.001	0.52
C18:1 *cis*-11, %	1.21	1.31	1.27	1.64	0.88	0.27	0.21	0.001	0.95
C18:2n-6, %	1.35	1.35	1.49	1.71	1.09	0.29	0.41	0.001	0.67
C18:2 *cis*-9, *trans*-11, %	0.78	0.87	0.90	0.53	1.17	0.26	0.08	0.001	0.64
C18:2 *cis*-11, *trans*-13, %	0.02	0.01	0.01	0.02	0.01	0.02	0.06	0.001	0.16
C18:2 *trans*-10, *cis*-12, %	0.01	0.01	0.01	0.01	0.01	0.0048	0.66	0.002	0.80
C18:2 *cis*, *cis*, %	0.08	0.08	0.08	0.03	0.13	0.032	0.78	0.001	0.56
C18:2 *trans*, *trans*, %	0.09	0.10	0.11	0.07	0.13	0.049	0.34	0.001	0.69
C18:3n-3, %	0.55	0.56	0.55	0.47	0.63	0.09	0.62	0.001	0.27
C20:4n-6, %	0.03	0.03	0.04	0.04	0.03	0.012	0.57	0.05	0.43
C20:5n-3, %	0.01	0.01	0.01	0.01	0.01	0.0047	0.32	0.001	0.38
C22:5n-3, %	0.05	0.05	0.05	0.03	0.07	0.018	0.14	0.001	0.16
C22:6n-3, %	0.01[b]	0.01[b]	0.02[a]	0.01	0.01	0.019	0.04	0.11	0.42
Unidentified, %	3.69	3.85	3.83	2.99	4.58	0.96	0.56	0.001	0.06
SFA, %	44.63	43.72	44.30	41.46	46.97	2.92	0.20	0.001	0.48
Odd-chain, %	2.08	2.04	2.07	1.94	2.18	0.34	0.96	0.09	0.80
MUFA, %	40.71	42.00	41.19	46.08	36.52	3.47	0.21	0.001	0.58
n-6 PUFA,%	1.39	1.38	1.53	1.74	1.12	0.30	0.40	0.001	0.66
n-3 PUFA, %	0.61	0.62	0.63	0.51	0.73	0.10	0.47	0.001	0.09
n-6:n-3 ratio	2.60	2.45	2.73	3.63	1.56	0.85	0.72	0.001	0.80

[a,b]Means with uncommon superscripts differ ($P < 0.05$).
[1]Stocker growth rate: low = 0.23 kg/d, medium = 0.45 kg/d, and high = 0.68 kg/d.
[2]Finishing system: CONC = high concentrate diet or PAST = pasture only.

fatty acid composition on a gravimetric basis (mg/85.5 g serving; Table 4). Total intake of myristic and palmitic acids per serving would be 656 mg greater for CONC than PAST. Stearic acid content per serving is less for PAST than CONC. Myrisitic and palmitic acids are considered to be hypercholesterolemic fatty acids, whereas stearic acid does not raise serum cholesterol (Bonanome and Grundy, 1988; Grundy, 1997). Total MUFA content per serving was 1,030 mg greater for CONC than PAST. Human diets high in MUFA have been shown to reduce low-density lipoprotein cholesterol without influencing high-density lipoprotein cholesterol (Grundy, 1989). Contents of n-6 fatty acids, linoleic, and arachidonic acids, were less for PAST than CONC. Content of linolenic, EPA, and DPA were greater by 13.3 mg for PAST compared with CONC. Howe et al. (2006) found that red meat products are a more substantial source of n-3 fatty acids in the human diet than was recognized. In addition, red meat sources supplied over 70% of total dietary DPA intake in the Australian diet where ruminants are typically forage-finished. de Lorgeril et al. (1994) conducted a dietary intervention study after a first myocardial infarction in patients participating in the Lyon Heart Study by reducing the linoleic acid to linolenic acid ratio to 4:1. At the end of 2 yr, patients on the intervention diet had less low-density lipoprotein cholesterol, greater high-density lipoprotein cholesterol, and a 76% decrease in total mortality. These results indicate that reducing the n-6 to n-3 ratio may reduce the risk of many chronic diseases (Simopoulos, 2008). *Trans*-11 vaccenic acid content in PAST was greater by 58.2 mg compared with CONC. Content of CLA, *cis*-9 *trans*-11 isomer, did not differ among finishing systems due to the greater fat content of the CONC-finished. However if we use the average conversion of *trans*-11 vaccenic acid to CLA in human adipose tissues (19%) reported by Turpeinen et al. (2002), then the predicted level of *cis*-9, *trans*-11 CLA due to the conversion of *trans*-11 vaccenic acid in the human body would effectively be 12.4 mg greater. Shen et al. (2007) reported a linear relationship among *trans*-11 vaccenic acid and *cis*-9 *trans*-11 CLA with coefficients of determination of 0.29 to 0.87 from the rumen to different tissues. Total fatty acid and hypercholesterolemic fatty acid contents per serving were 2.0 and 0.66 g less, respectively, for PAST than CONC. Beef from CONC-finished has a

Table 4. Fatty acid content per serving (mg/85.5-g serving) of beef ribeye steak by finishing system

	Finishing system[2] (F)			
Fatty acid, mg/85.5-g serving[1]	CONC	PAST	SE	*F*-value
n	103	95		
SFA				
Myrisitic and palmitic acids	1,237	581	331.0	0.001
Stearic acid	580	370	186.4	0.001
MUFA	1,760	730	508.8	0.001
PUFA, n-6				
Linoleic acid	115	54	22.6	0.001
Arachidonic acid	27	19	5.2	0.001
PUFA, n-3				
Linolenic acid	16	22	6.3	0.001
Eicosapentaenoic	4.1	8.4	2.0	0.001
Docosapentaenoic	10	13	2.8	0.001
Docosahexaenoic	1.6	1.4	0.74	0.13
Trans-11 vaccenic acid	14.2	72.4	24.8	0.001
CLA, *cis*-9, *trans*-11 isomer	15.6	17.0	7.4	0.30
CLA, *cis*-9, *trans*-11 isomer[3]	18.3	30.7	11.2	0.001
Total fatty acid content	4,161	2,127	1,162.2	0.001

[1]mg/85.5-g serving: calculated based on approximation of 25% cooking loss [114 g raw approximates 85.5 g (3 oz) cooked].

[2]Finishing system: CONC = high concentrate diet or PAST = pasture only.

[3]CLA, *cis*-9, *trans*-11 isomer: includes average conversion of *trans*-11 vaccenic acid to *cis*-9, *trans*-11 CLA according to Turpeinen et al. (2002; 19%).

greater total fatty acids, SFA, and MUFA content; in contrast, beef from PAST-finished has less total, SFA, and MUFA content with greater contents of n-3 fatty acids and a decreased n-6 to n-3 ratio. Beef from PAST-finished also has greater contents of B-vitamins and antioxidants (vitamin E and β-carotene).

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