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Effects of forage species or concentrate finishing on animal performance, carcass and meat quality[1,2]

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ABSTRACT: Angus-cross steers (n = 128; initial BW = 270 ± 3.8 kg) were used in a 3-yr study to assess effects of forage species grazed before slaughter versus concentrate finishing on carcass and meat quality. At the completion of the stockering phase, steers were randomly allotted to mixed pasture (MP; n = 36/yr) or corn-silage concentrate (CON; n = 12/yr) finishing treatments. At 40 d before harvest, MP steers were randomly divided into 3 forage species treatments: alfalfa (AL), pearl millet (PM), or mixed pasture (MP). Average daily BW gain was greater (P = 0.001) for CON than for forage-finished (FOR) steers during the early and overall finishing phase. During the late finishing phase when FOR steers were grazing difference forage species, ADG was greater (P = 0.03) for PM than MP or AL. Harvest weight and HCW were greater (P < 0.001) for CON than FOR due to the differences in animal performance. Total fat percentage of the 9th to 11th rib section was 46% less(P = 0.028) for FOR than CON due to reductions (P < 0.001) in the percentage of subcutaneous fat. Warner-Bratzler shear force (WBS) values at 14 d and 28 d of aging did not differ (P > 0.78) between CON and FOR and were not altered (P > 0.40) by forage species. Trained sensory panel juiciness, initial tenderness, and overall tenderness scores did not differ (P > 0.17) by finishing treatment or forage species. Beef flavor intensity was greater (P < 0.001) for CON than FOR. Beef flavor intensity was greater (P < 0.02) for AL and PM than MP. Off-flavor intensity was greater (P < 0.001) for all forage-fed steaks, regardless of forage species, than CON. Finishing on forages reduced (P = 0.003) total lipid content by 61% for the LM compared with CON finished cattle. Forage species grazed before harvest did not alter (P > 0.05) total lipid content of the LM. Oleic acid concentration and total MUFA of the LM were 21% and 22% less (P = 0.001) for FOR than CON. Concentrations of all individual [linolenic acid, eicosapentaenoic (EPA), docosapentaenoic (DPA), and docosadexaenoic (DHA) acids] and total n-3 fatty acids were greater (P < 0.001) for FOR than CON. Finishing on AL increased (P = 0.017) the concentration of linolenic acid compared with MP or PM. The ratio of n-6 to n-3 fatty acids was greater (P = 0.001) for CON than FOR and did not differ (P = 0.88) by forage species. Concentrate finishing increases carcass weight with same time endpoints and accelerates deposition of MUFA in comparison with FOR, which reduces carcass weight and fat deposition but maintains high concentrations of n-3 and CLA fatty acids. Finishing system or forage species grazed 40 d before slaughter did not alter beef tenderness but FOR had greater off-flavors according to both trained and descriptive sensory panelists.

Key words: beef, fatty acids, forage, proximate

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INTRODUCTION

Previous research (Duckett et al., 2007, 2009b; Neel et al., 2007) has shown that finishing steers on forages instead of concentrates results in leaner car-

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casses with greater concentrations of n-3 fatty acids and CLA when finished at similar animal ages. However, the use of different forage species in forage-finishing systems has received limited attention. Forage fatty acid content is variable among species, variety, harvest time, and growing season (Dewhurst et al., 2001; Clapham et al., 2005), and influences meat and milk fatty acids of grazing animals (Dewhurst et al., 2003). Therefore, research is needed to examine how improved forages used in a forage-finishing system, especially immediately before slaughter, can alter beef quality and composition.

In lambs, research shows that the forage species consumed immediately before harvest (4 to 6 wk) can alter flavor intensity and consumer acceptability (Duckett and Kuber, 2001). Grazing of legumes, white clover (Cramer et al., 1967; Shorland et al., 1970), or alfalfa (Nicol and Jagusch, 1971; Park et al., 1972) before slaughter increased odor and off-flavor scores in lamb. However, limited research is available comparing short-term grazing of different forage species before slaughter on beef quality and flavor. Forage-finished beef is typically rated as having reduced beef flavor and greater off-flavor scores by trained sensory panelists compared with concentrate-finished beef (Larick et al., 1987; Larick and Turner, 1989; Duckett et al., 2009b). Forage systems used for finishing must not negatively impact beef flavor parameters or consumer acceptability. This study was designed to examine how short-term (40 d) grazing of different forage species (traditional grasses vs. legumes or annual grasses) immediately before slaughter alters carcass and meat quality in forage-finished steers compared with concentrate-finished controls.

MATERIALS AND METHODS

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

Angus-cross steers (n = 128; in BW = 270 ± 3.8 kg) were used in a 3-yr study to assess changes in carcass and meat quality with forage species grazed before slaughter compared with concentrate finishing. Before the start of this experiment, steers grazed a forage-only stockering program after weaning. Steers were randomly allotted to finishing treatments:mixed pasture (**MP**; n = 36/yr) or corn-silage concentrate (**CON**; n = 12/yr). The feedlot-finishing diet consisted of (DM basis) 18.0% corn silage, 76.0% shell corn, 5.6% soybean meal, 0.14% limestone, 0.23% trace mineralized salt (Champions Choice; Cargill Inc., Minneapolis, MN), and 20,000 IU of vitamin A head^{-1}·d^{-1}. Step-up diets were used to bring the cattle to full feed during the feedlot finishing. Nutritive values for the feedlot diet (DM basis) were 10.5% CP, 6.5% ADF, and 16.8% NDF.

At 40 d before harvest, MP steers were randomly divided into 3 forage species treatments: alfalfa (**AL**, *Medicago sativa* L.), pearl millet (**PM**; *Pennisetum americanum* L.), or MP. Mixed pastures consisted of a mix of bluegrass (*Poapratensis* 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. In yr 3, steers could not graze PM treatment due to high nitrate concentrations in the forage as a result of drought; thus, results for PM are for the first 2 yr of grazing only. Steers on forage (**FOR** = MP, PM, and AL) and CON treatments were finished to an equal time endpoint each year (134 d for yr 1, 138 d for yr 2, and 124 d for yr 3) to minimize confounding due to animal age; forage species treatments were grazed for the final 40 d of the FOR finishing period (i.e., 94 to 134 in yr 1). No anabolic implants or ionophores were used in this experiment.

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 rib section (107 Beef Rib; NAMP, 1988) from the left side of each carcass were identified, removed, vacuum-packed, and transported to Clemson University Meat Laboratory. Upon arrival at the meat laboratory, rib sections were maintained at 4°C until 14 d of postmortem aging was complete. After 14 d of postmortem aging, the rib sections were removed from vacuum packaged bags and allowed to bloom for at least 30 min.

Rib Composition

The whole beef rib (NAMP 107; 10.16 cm tail; untrimmed) was weighed, and the 9–10–11th rib section was removed and weighed. The external fat covering [subcutaneous (**s.c.**) fat] was removed from the 9–10–11th rib section and weighed. Then the LM was removed from the 9–10–11th rib section and weighed. The remaining rib section was dissected into lean trim, fat, and bone, and each were weighed. Samples of LM taken from the 11th rib were lyophilized, ground, and stored at -20°C for subsequent crude fat, proximate analysis, and fatty acid composition. Lean trim (not including LM) was ground individually and mixed thoroughly for subsequent crude fat determination. Crude fat content was determined in LM and lean trim samples in triplicate using an Ankom XT-15 extractor (ANKOM Technologies, Macedon, NY)with hexane as the solvent. Crude fat content was subtracted from LM and lean trim weights and added to intermuscular/intramuscular (**i.m.**) weights for fat-free lean calculations. Results from the

9–10–11th rib dissection were used to calculate carcass composition according to Lunt et al. (1985). Steaks (2.54 cm thick) were obtained from the LM (9–10–11th rib section) for subsequent total fat content, Warner-Bratzler shear force measurement, and trained sensory panel analyses.

Instrumental Color

Instrumental color measurements were recorded for L* (measures darkness to lightness; lower L* indicates a darker color), a* (measures redness; greater a* value indicates a redder color), and b* (measures yellowness; greater b* value indicates a more yellow color) using a Minolta chromameter (CR-310; Minolta Inc., Osaka, Japan) with a 50-mm-diameter measurement area using a D65 illuminant, which was calibrated using the white ceramic disk provided by the manufacturer. Color readings were determined at 14-d postmortem on the exposed LM at the posterior (12th rib) of the rib and s.c. fat covering the posterior rib. Values were recorded from 3 locations of exposed lean and s.c. fat to obtain a representative reading.

Warner-Bratzler Shear Force

Two steaks (2.5-cm thick) were removed from the LM (10th rib) and vacuum packaged after dissection. One steak was immediately frozen at -20°C (14 d of aging) and the other steak was aged at 4°C for an additional 14 d and frozen at -20°C (28 d of aging). Steaks were frozen for approximately 30 d before shear force analyses. Steaks (2.5-cm thick) were thawed for 24 h at 4°C and broiled on Farberware (Bronx, NY) electric grills to an internal temperature of 71°C (AMSA, 1995). Steaks were allowed to cool to room temperature before six 1.27-cm-diameter cores were removed from each steak parallel to the longitudinal orientation of the muscle fibers. All cores were sheared perpendicular to the long axis of the core using a Warner-Bratzler shear machine (G-R Manufacturing, Manhattan, KS).

Trained Sensory Panel Evaluation

Steaks (2.54-cm thick) for sensory panel evaluation were obtained from the LM (9th rib), aged at 4°C for a total of 14-d postmortem and frozen at -20°C. Steaks were frozen for approximately 42 d before sensory analyses. Steaks were thawed for 24 h at 4°C and broiled on Farberware electric grills to an internal temperature of 71°C (AMSA, 1995). Steaks were immediately cut into 2.54 cm × 1.27 cm × 1.27 cm cubes and served warm to an 8-member sensory panel (AMSA, 1995). Panelists were recruited verbally and selected based on willingness to serve at scheduled times and interest in evaluation of beef steaks. Potential panelists were screened on several steak samples and chosen to serve based on abilities to discriminate known differences in tenderness, juiciness, and flavor. The sensory panel trained for several weeks on the sensory attributes and scoring system, and performance was evaluated for continued inclusion in the sensory analyses. Each panelist evaluated 2 cubes from each sample for juiciness, initial tenderness, overall tenderness, and beef flavor intensity using an 8-point scale (1 = extremely dry, tough, and bland to 8 = extremely juicy, tender, and intense). Off-flavor scores were also recorded on a 9-point scale (0 = none, 1 = extremely slight off-flavor to 8 = extremely intense off-flavor).

Descriptive Flavor Panel

Steaks (n = 94; 2/steer; yr 2 only) were shipped frozen via overnight mail to Kansas State University Sensory Analysis Center in Manhattan, KS, for descriptive flavor and texture analysis. A panel of 5 highly trained descriptive panelists evaluated the samples. Panelists had 4.5 h of orientation to develop attributes and testing procedure. Flavor and texture attributes of the samples were identified and the intensities were quantified using a 15-point scale with 0.5 increments (0.0 = none, 0.5 to 5.0 = slight, 5.5 to 10.0 = moderate, 10.5 to 15.0 = extreme). References for each attribute were used to calibrate the measurements. Steaks (shipped frozen to Kansas State University overnight) were maintained frozen, and thawed in the refrigerator (4°C) for 24 h in advance of preparation. All samples were prepared using a Wells Countertop Electric Char-Broiler (Wells Manufacturing Co., Verdi, NV). Steaks were placed on grill and turned every 4 min until an internal temperature of 71°C was reached. Internal cooking temperature was monitored using a Cole Parmer DigiSense Scanning Thermometer (Model 92000–05 Benchtop 230V) and type K penetration thermocouples (Cole Parmer, Vernon Hills, IL). After the steaks reached the desired endpoint temperature, they were cut into 0.5 in pieces and served immediately on heated bricks to minimize cooling. Each panelist was served 4 to 5 pieces of steak. Samples were presented monadically and coded with random 3-digit numbers. Panelists used a computerized data collection system (Compusense Five, v. 4.4.7, 2002; Guelph, ON, Canada) for data entry.

Proximate Composition

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. Samples of LM from each rib/carcass were pulverized in liquid nitrogen and stored at -20°C.

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 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 Gimeno et al. (2000) and Lee et al. (2005). Recovery rates were 84% for tocopherol and 80% for β-carotene. Briefly, LM samples were saponified in sodium hydroxide, extracted with hexane, evaporated and redissolved in methanol. For tocopherol, a 15-μL sample was injected into a HPLC (Shimadzu Prominence, Columbia, MD), separated with a 15 cm × 4.6 mm Discovery RP-Amide C16 column (Sigma-Aldrich, St. Louis, MO) and eluted by an isocratic mobile phase of methanol-water (97:3) for tocopherol at 1 mL/min. Concentrations of α-tocopherol were detected using a Shimadzu Fluorescence Detector (RF-10aXL; Shimadzu America, Columbia, MD) with excitation of 295 nm and emission of 325 nm, and quantified based on response of standard curve (0 to 8 ug/mL). For β-carotene, a 100-μL sample was injected into the HPLC, separated with Discovery RP-Amide C16 column, and eluted by an isocratic mobile phase of methanol-butanol (92:8) at 1 mL/min. Concentrations were detected using a Shimadzu SPD-M20A Diode Array detector (Shimadzu America) at 295 to 473 nm, and quantified based on response of standard curve (0 to 0.2 ug/mL).

Fatty Acid Composition

Longissimus muscle samples were frozen, lyophilized, and ground in a food processor. Total fat content was determined on LM lyophilized samples in duplicate using Ankom XT-15 Extractor (Ankom Technology, Macedon, NY) and hexane as solvent. Freeze-dried samples were transmethylated according to the method of Park and Goins (1994). Fatty acid methyl esters (**FAME**) were analyzed using an Agilent 6850 (Agilent, SantaClara, CA) gas chromatograph equipped with an Agilent 7673A (Agilent) automatic sampler. Separations were accomplished using a Supelco 100-m SP2560 (Sigma-Aldrich, St. Louis, MO) 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 minute, from 160 to 167°C at 0.2°C per min, from 167 to 225°C at 1.5°C per minute, 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 minute. Samples were run twice with a split ratio of 100:1 for trans C18:1 and long-chain fatty acids and again at split ratio of 10:1 for CLA and omega-3 fatty acids. Individual fatty acids were identified by comparison of retention times with standards (Sigma-Aldrich; Matreya, Pleasant Gap, PA). Fatty acids were quantified by incorporating an internal standard, methyl tricosanoic (C23:0) acid, into each sample during methylation and expressed as a weight percentage of total fatty acids.

Statistical Methods

Comparisons Among Forage Finishing. Statistical analyses were conducted using Genstat (Genstat Fourteenth Edition, 2011; The Numerical Algorithms Group, Inc., Lisle, IL).

For those steers finished on pasture, the design variables were harvest year (2005, 2006, and 2007) and finishing treatment (MP, AL, and PM). Within a harvest year, 12 calves were randomly assigned to a forage treatment. Finishing treatments were divided among 3 paddocks (or blocks), with 4 steers per paddock. Thus paddock was the experimental unit. As noted earlier, due to drought in 2007, the PM treatment was excluded.

The REML procedure was used to fit a mixed linear model of the form:

$$Y_{ijkl} = \mu + F_i + B_j + e^A_j + S_{(j)k} + \mathbf{X}\hat{\mathbf{a}} + e^B_{ijkl}, \quad [1]$$

where Y_{ijkl} was the response variable for a steer (l = 1 to 4) randomly assigned to a forage treatment F (j = 1 to 3) in block B (i = 1 to 3) in harvest year S (k = 1 to 3). The design matrix, **X**, related the levels of covariates to the steers to which they pertained, and β was a vector of linear regression coefficients. The μ was the overall mean. The random terms were block (B_i), block by forage treatment interaction (e^A_{ij}), harvest year nested within the block by forage treatment interaction [$S_{(ij)k}$], and residual error (e^B_{ijkl}). Age when placed on a pasture forage treatment [mean 531 (SD 18) d], and days on that forage treatment [mean 40 (SD 8) d], were fitted as linear covariates. When evaluating ADG, days on forage treatment was excluded as a covariate.

In a single year, 8 trained sensory panelists scored grilled cubes from the LM for juiciness, initial tenderness, overall tenderness, and beef flavor intensity. For

these data, REML was again used but to fit a model of the form:

$$Y_{ijkl} = \mu + F_i + B_j + e^A_j + A_{(j)k} + \mathbf{X}\hat{\mathbf{a}} + P_l + e^B_{ijkl}\ , \quad [2]$$

where Y_{ijkl} was the sensory score for a panelist (l = 1 to 8) for a steer (k = 1 to 4) randomly assigned to a forage treatment F (j = 1 to 3) in a block B (i = 1 to 3). As with model [1], **X** was the design matrix, β was a vector of linear regression coefficients, and μ was the overall mean. The random terms were block (B_l), block by forage treatment interaction (e^A_{ij}), steer nested within the block by forage treatment interaction [$A_{(ij)k}$], panelist (P_l), and residual error [$e^B_{(ij)kl}$].

Means were compared using Fisher's protected least significance difference test. That is, differences among means were only tested when the fix effect of forage treatment itself defined sufficient variation in the response variable ($P < 0.05$).

Comparison of Forage and Concentrate Finishing. Performance levels of steers finished on concentrates was compared with those on forage. The design variables were harvest year (2005, 2006, and 2007) and either forage or concentrate finishing. In 2005 and 2006, 11 calves were finished in the feedlot; in 2007 there were 10 calves. Because the feedlot calves were housed together, there was no consistent paddock (or housing) effect across all treatments (as in model [1]). Therefore harvest year within finishing treatment was used as the experimental unit.

The REML procedure was used to fit a mixed linear model of the form:

$$Y_{ijk} = \mu + C_i + S_{(i)j} + \mathbf{X}\hat{\mathbf{a}} + e_{ijk}\ , \quad [3]$$

where Y_{ijk} was the response variable for a steer (k), randomly assigned to a forage or concentrate finishing treatment C (i = 1 or 2) in harvest year S (j = 1 to 3). The design matrix, **X**, related the levels of covariates to the steers to which they pertained, and β was a vector of linear regression coefficients. The μ was the overall mean. The random terms were harvest year nested within finishing treatment [$S_{(i)k}$], and residual error [$e_{(ij)k}$]. Age at the start of finishing [mean 398 (SD) 19 d], and days on finishing treatment [mean 132 (SD 13) d], were fitted as linear covariates. When evaluating ADG, days on finishing treatment was excluded as a covariate.

An abridged model was fitted to analyze the trained sensory panel data. Using REML, the model fitted was of the form

$$Y_{ijk} = \mu + C_i + A_{(i)j} + \mathbf{X}\hat{\mathbf{a}} + P_k + e_{ijk}\ , \quad [4]$$

where Y_{ijk} was the sensory score for a panelist (k = 1 to 8) for a steer (j) randomly assigned to a forage treatment C (i = 1 or 2). As in model [3], **X** was the design matrix, β was a vector of linear regression coefficients, and μ was the overall mean. The random terms were steer nested within forage treatment [$A_{(i)j}$], panelist (P_k), and residual error (e_{ijk}).

For some response variables, the SD of the 3 forage treatment categories, or the concentrate and combined forage treatment category, appeared to differ and often scaled proportionally with the mean. Homogeneity of the residual variance among treatment categories from the fit of model [1] to [4] was assessed using Bartlett's test (Snedecor and Cochran, 1980). Where heterogeneous ($P < 0.05$), the data were log transformed, model [1] to [4] fitted as appropriate, and the residual variances tested for homogeneity. With few exceptions, the log transformation stabilized the residual variances. Even for cases where heterogeneity remained, it was quantitatively small. Furthermore, because significance levels for mean comparisons were the same for the original and log scaled data, only results on the observed scale are reported.

When fitting models [1], [2], and [3], negative estimates of the variance were obtained for some of the random terms for some response variables. In those cases, relationships among mean squares were inconsistent with expectations. As this was not sensible, the relevant model was fitted again including only those random terms that had a positive estimate for their variance component and gave the expected relationships among the mean squares. When fitting these reduced models, the numerical values predicted for the design variables were not affected nor were the conclusions drawn from hypothesis tests.

Data from the descriptive flavor panel were analyzed by the Kansas State Sensory Analysis Center using analysis of variance (Proc Glimmix; SAS Inst. Inc., Cary, NC) at the 95% confidence interval to determine if there were significant differences ($P < 0.05$) for finishing treatments when the F-test was significant.

RESULTS AND DISCUSSION

Average daily BW gain was greater ($P = 0.001$) for CON than for FOR steers during the early (+46%) and overall (+36%) finishing phase (Table 1). During the late finishing phase when FOR steers were grazing different forage species, ADG was greater ($P = 0.03$) for PM than MP or AL. Harvey and Burns (1988) reported that greater calf BW gains when creep intensively grazed pearl millet than red clover/bluegrass mixtures. Hot carcass weight tended ($P = 0.092$) to differ between forage species, mirroring ADG during late finishing. Harvest

weight and HCW were greater ($P < 0.001$) for CON than FOR due to differences in animal performance. Others also (Crouse et al., 1984; Bennett et al., 1995; Neel et al., 2007) reported lighter carcass weights of forage-finished steers compared with concentrate-fed when finished to similar time endpoints. Dressing percentage was also greater ($P < 0.001$) for CON than for FOR steers. Concentrate-finished steers had greater ($P < 0.01$) stores of fat in the carcass including increased fat thickness at 12th rib, KPH, and marbling scores than did FOR. Ribeye area was larger ($P = 0.004$) for CON than FOR; however, the percentage of boneless, closely-trimmed, retail cuts (**BCTRC**) was less ($P = 0.01$) for CON than FOR due to greater fat content of the carcass. These results are in agreement with our previous research (Duckett et al., 2007; Neel et al., 2007) comparing CON and FOR steers. Finishing on different forage species for 40 d before slaughter (MP, PM, or AL) did not alter ($P > 0.27$) KPH, ribeye area marbling score, or BCTRC.

The 9–10–11th rib section weight was heavier ($P < 0.001$) for CON than FOR (Table 2). The percentage of fat-free lean, including the LM and other lean trim, tended to be greater ($P < 0.09$) for FOR than CON. Total fat percentage of the 9–10–11th rib section was 46% less ($P = 0.028$) for FOR than CON due to reductions ($P < 0.001$) in the percentage of s.c. fat. Earlier research evaluating 9–10–11th rib composition by growth rate and finishing system showed similar reductions (42%) in s.c. fat for forage compared with concentrate-finished beef (Duckett et al., 2007). Percentages of intermuscular and i.m. fat tended ($P = 0.062$) to be lower in FOR than CON. The percentage of total bone in the 9–10–11th rib section was greater ($P = 0.032$) for FOR than CON. Finishing on different forage species for 40 d before slaughter did not alter ($P > 0.10$) 9–10–11th rib weight or composition even though animal gains were improved with finishing on PM.

Predicted carcass composition from the 9–10–11th rib dissection data according to Lunt et al. (1985) is shown in Table 2. Carcasses from steers finished on FOR, regardless of forage species, had lower ($P = 0.028$) percentage of fat and greater ($P = 0.032$) percentage of bone than CON. These differences equate to 48 kg less fat per carcass for FOR compared with CON. Carcasses from steers finished on FOR also tended ($P = 0.085$) to have greater percentage of carcass lean. Forage species grazed during the final 40 d of finishing did not alter ($P > 0.23$) predicted carcass composition in this study. Our results on carcass composition prediction agree with others (Crouse and Dikeman, 1976; Dikeman et al., 1998; Duckett et al., 2007). In contrast, Lunt et al.

Table 1. Least squares means for finishing treatment on pre-harvest and carcass measures[1]

	Forage species[1]					Finishing system[1]			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
No. animals	36	36	24			32	96		
ADG									
Early finishing, kg/d	n/a	n/a	n/a			1.67[c]	0.91[d]	0.10	0.001
Late finishing, kg/d	1.11[b]	1.15[b]	1.61[a]	0.13	0.032	1.17	1.26	0.14	0.534
Overall finishing, kg/d	n/a	n/a	n/a			1.56[c]	0.99[d]	0.10	0.004
Harvest wt[4], kg	479	480	493	10	0.397	587[c]	484[d]	7	< 0.001
HCW, kg	246	252	261	5	0.092	352[c]	252[d]	6	< 0.001
Dressing[4], %	53.4[b]	54.8[a]	55.0[a]	0.4	0.003	62.3[c]	54.3[d]	0.6	< 0.001
KPH, %	1.60	1.48	1.62	0.10	0.275	2.22[c]	1.56[d]	0.16	0.021
Fat thickness[5], cm	0.542	0.541	0.598	0.073	0.701	1.371[c]	0.557[d]	0.092	0.002
Rib-eye area[5], cm^2	63.5	64.6	66.5	2.0	0.402	83.3[c]	64.9[d]	2.5	0.004
Marbling score[6]	402	410	421	14	0.465	657[c]	409[d]	13	< 0.001
BCTRC[7], %	51.6	51.7	51.7	0.2	0.965	49.6[d]	51.6[c]	0.4	0.013

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON). Forage-finished (FOR) steers represent an average of forage species treatments.

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[4]Adjusted to 4% shrink in harvest weight.

[5]At the 12th rib.

[6]Marbling score: numerical score with 100 point subunits where Abundant90 valued 1090 and Practically Devoid00 valued 200.

[7]BCTRC = boneless, closely trimmed retail cuts.

[a,b]For forage finishing treatments, means in the same row with uncommon superscripts differ ($P < 0.05$).

[c,d]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

Table 2. Least squares means for finishing treatment on ninth to 11th rib section weight and carcass composition[1]

	Forage species[1]					Finishing system[1]			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
No. animals	36	36	24			32	96		
9–10–11th Rib section wt, kg	3.18	3.29	3.27	0.07	0.224	5.27[a]	3.25[b]	0.13	< 0.001
9–10–11th Rib section composition									
Fat-free lean, %	51.8	53.2	51.2	1.3	0.372	41.0	52.6	4.8	0.085
Fat-free LM, %	26.1	25.9	26.0	0.6	0.791	20.5	26.2	2.1	0.068
Fat-free other lean, %	25.7	27.3	25.2	1.2	0.259	20.5	26.3	2.3	0.087
Total fat, %	18.6	17.8	19.2	1.2	0.558	34.2[a]	18.3[b]	4.3	0.028
Subcutaneous fat, %	8.87	8.27	8.65	0.63	0.610	13.5[a]	8.6[b]	0.3	< 0.001
Intermuscular and intramuscular fat, %	9.76	9.52	12.1	0.82	0.106	20.7	9.8	4.1	0.062
Total bone, %	29.4	28.9	28.7	0.5	0.257	24.8[b]	29.1[a]	1.2	0.032
Predicted carcass composition[4]									
Carcass lean, %	62.8	63.6	62.5	0.7	0.372	56.9	63.3	2.7	0.085
Carcass fat, %	13.7	13.2	14.8	0.8	0.239	23.3[a]	13.5[b]	2.7	0.028
Carcass bone, %	23.1	22.8	22.7	0.3	0.257	20.4[b]	22.9[a]	0.7	0.032

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON). Forage-finished (FOR) steers represent an average of forage species treatments.

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[4]Calculated according to Lunt et al. (1985).

[a,b]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

(1985) did not observe a difference in actual carcass percent separable fat between grain- and forage-fed cattle when slaughtered at the same BW endpoint.

Longissimus muscle color of CON was lighter (greater L*; $P = 0.009$; Table 3) than FOR. Longissimus muscle pH was greater ($P = 0.008$) for FOR than CON. Others have reported darker lean color scores for forage-finished vs. grain-finished beef in the U. S. (Crouse et al., 1984; Bennett et al., 1995; Duckett et al., 2007), Uruguay (Realini et al., 2004), and Ireland (Dunne et al., 2006). Bidner et al. (1986) reported darker lean color in forage-finished beef without any changes in muscle pH values. Longissimus muscle a* and b* values did not differ ($P > 0.11$) between FOR and CON. Subcutaneous fat L* values did not differ ($P = 0.69$) among finishing treatments. Subcutaneous fat b* (yellowness) values were greater ($P = 0.001$) for FOR versus CON. Subcutaneous fat a* (redness) values were greater ($P = 0.023$) for CON than FOR. Forage species grazed during the final 40 d did not alter s.c. or LM color values, or LM pH. Others (Bennett et al., 1995; Duckett et al., 2007) have reported similar changes in LM and s.c. color scores for beef fin-

Table 3. Least squares means for finishing treatment for LM color and pH, and subcutaneous fat color[1]

	Forage species[1]					Finishing system[1]			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
No. animals	36	36	24			32	96		
LM									
L*	39.34	40.89	39.77	0.93	0.274	43.20[a]	40.05[b]	0.68	0.009
a*	23.28	24.15	24.02	0.55	0.221	25.44	23.81	0.77	0.110
b*	9.48	10.14	10.05	0.31	0.093	10.95	9.83	0.70	0.198
pH	5.68	5.61	5.63	0.08	0.675	5.49[a]	5.64[b]	0.04	0.008
Subcutaneous fat									
L*	73.57	72.62	72.75	0.55	0.156	73.27	72.95	0.74	0.686
a*	8.91	9.50	9.91	0.71	0.433	11.37[a]	9.39[b]	0.52	0.023
b*	18.58	18.34	18.80	0.33	0.395	14.44[b]	18.52[a]	0.50	0.001

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON). Forage-finished (FOR) steers represent an average of forage species treatments.

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[a,b]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

ished under these different production systems. Forage species grazed during the final 40 d also did not alter ($P > 0.09$) LM or s.c. color values.

Warner-Bratzler shear force (**WBS**) values at 14 d and 28 d of aging did not differ ($P > 0.78$; Table 4) between CON and FOR. Forage species grazed during the final 40 d also did not alter ($P > 0.40$) WBS values for 14- or 28-d of postmortem aging. These data suggest that finishing system does not alter beef tenderness when steers are slaughtered at similar time endpoints, regardless of final BW or composition. Similarly, others have reported no changes in beef tenderness of forage-finished vs. concentrate-finished beef when finished to an equal animal age (Mandell et al., 1998; Realini et al., 2004; Duckett et al., 2009b), similar fat thickness endpoint (Crouse et al., 1984; Muir et al., 1998), or similar BW endpoint (Bidner et al., 1981, 1986). In contrast, others (Bowling et al., 1977; Hedrick et al., 1983; Bennett et al., 1995) have reported increased shear force and decreased sensory tenderness ratings for forage-finished beef when finished to similar BW endpoints in which forage-finished cattle are older.

Trained sensory panel juiciness, initial tenderness, and overall tenderness scores did not differ ($P > 0.17$) by finishing treatment or forage species (Table 4). Beef flavor intensity was greater ($P < 0.001$) for CON than FOR. Beef flavor intensity was greater ($P = 0.019$) for AL, and PM than MP. Off-flavor intensity was greater ($P < 0.001$) for all forage-fed steaks, regardless of forage species, than CON. Mandell et al. (1998) also observed decreased beef flavor scores and greater off-flavor scores in forage-finished compared with concentrate-finished beef. Realini et al. (2009) reported that acceptability of forage-finished vs. concentrate-finished beef depends on consumer preference, as certain countries ranked forage-finished beef greater. Forage species grazed before finishing did not alter ($P < 0.001$) off-flavor intensity. Others (Cramer et al., 1967; Shorland et al., 1970; Nicol and Jagusch, 1971; Park et al., 1972) have reported that legumes can impart off-flavors in lamb when grazed before slaughter. Thus, finishing on alternate forage species (AL or PM) just before slaughter did not negatively impact off-flavor scores compared with MP in this study, which indicates that improved forage varieties can be used in forage-finishing systems for improved animal performance without negative impacts on beef flavor.

Due to the differences observed in off-flavor intensity scores by finishing treatments, samples in yr 2 were sent to the Kansas State University Sensory Laboratory for descriptive flavor panel analyses (Table 5). Juiciness score was greater ($P = 0.01$) for CON than all forage-finished treatments. Mealy scores were less ($P = 0.02$) for CON than all forage-finished treatments. Beef flavor ID was greater ($P = 0.001$) for CON than all forage-fed

Table 4. Least squares means for finishing treatment for longissimus muscle Warner-Bratzler shear force and trained sensory panel scores[1]

	Forage species[1]					Finishing system[1]			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
Warner-Bratzler shear force, kg									
No. observations	36	36	24			32	96		
d 14 postmortem	2.64	2.63	2.70	0.09	0.750	2.70	2.66	0.14	0.780
d 28 postmortem	2.67	2.52	2.61	0.12	0.396	2.62	2.61	0.16	0.955
Trained sensory panel scores (yr 1 only)									
No. animals	12	12	12			12	36		
Juiciness[4]	4.78	5.14	4.94	0.53	0.807	4.49	4.96	0.34	0.172
Initial tenderness[4]	5.33	6.04	5.73	0.24	0.124	5.56	5.70	0.28	0.601
Overall tenderness[4]	5.40	6.14	5.75	0.23	0.107	5.55	5.76	0.31	0.507
Beef flavor intensity[4]	3.56[b]	3.94[a]	3.82[a]	0.09	0.019	4.79[c]	3.77[d]	0.16	< 0.001
Off-flavor intensity[5]	3.18	2.77	2.94	0.30	0.451	2.08[d]	2.71[c]	0.14	< 0.001

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON). Forage-finished (FOR) steers represent an average of forage species treatments.

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[4]8-point scale: 1 = extremely dry, tough, and bland to 8 = extremely juicy, tender and intense.

[5]9-point scale: 0 = none, 1 = extremely slight off-flavor to 8 = extremely intense off-flavor.

[6]Descriptive flavor analysis: 15 point scale with 0.5 increments (0 = none, 0.5–5 = slight, 5.5–10 moderate, 10.5–15.0 = extreme).

[a,b]For forage finishing treatments, means in the same row with uncommon superscripts differ ($P < 0.05$).

[c,d]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

treatments. Organ meat flavor was ranked greater ($P < 0.05$) for MP than AL, PM, or CON. Off-note flavor scores were greater ($P = 0.02$) for MP and AL than CON with PM being intermediate. Sour flavor scores were greater ($P = 0.05$) for forage-finished treatments than CON. Initial tenderness, chewiness, fiber awareness, residual connective tissue, brown roasted flavor, blood/serumy, rancid, salty, and bitter scores did not differ ($P > 0.10$) among finishing treatments. Results from this descriptive flavor panel did not pinpoint what flavor notes were present in forage- versus concentrate-finished beef that are contributing to the greater off-note flavors. The only difference in sensory scores among forage finishing systems was for MP having a greater organ meat flavor and greater overall off-note flavor scores compared with AL or PM. No relationships between these flavor scores and muscle pH, mineral content, or fatty acid composition were observed in this study. Additional research is needed to examine volatile flavor profiles in beef produced under these finishing systems and their relationship to the observed off-flavor scores in forage-finished beef.

Table 5. Least squares means for finishing treatment on descriptive flavor analyses (yr 2 only)

	Finishing treatments[2]				
Variable[1]	MP	AL	PM	CON	*P*-value
No. animals	12	12	12	11	
Juiciness	5.41[b]	5.63[b]	5.51[b]	5.91[a]	0.01
Initial tenderness	10.68	10.78	10.17	10.66	0.14
Chewiness	7.49	7.44	7.76	7.46	0.45
Mealy	2.03[a]	2.05[a]	1.92[a]	1.57[b]	0.02
Fiber awareness	6.47	6.49	6.65	6.38	0.60
Residual connective tissue	1.98	2.01	2.24	1.87	0.20
Beef flavor ID	9.99[b]	10.30[b]	10.38[b]	11.12[a]	0.001
Brown roasted	11.61	11.61	11.61	11.68	0.97
Organ meat	0.31[a]	0.12[b]	0.08[b]	0.07[b]	0.01
Blood/Serumy	2.85	2.98	2.91	2.94	0.42
Metallic	2.85	2.98	2.91	2.95	0.45
Rancid	0.13	0.13	0.13	0.08	0.93
Off-note	0.77[a]	0.71[a]	0.57[ab]	0.18[b]	0.02
Sour	2.14[a]	2.11[a]	2.10[a]	2.01[b]	0.05
Salty	1.63	1.64	1.62	1.77	0.36
Bitter	2.74	2.68	2.67	2.54	0.20

[1]15 point scale with 0.5 increments: 0.0 = none, 0.5 to 5 = slight, 5.5 to 10 = moderate, and 10.5 to 15 extreme. Textural attributes were defined as follows: initial tenderness = ease with which sample can be cut through molars on first bite; juiciness = the amount of liquid expressed from sample at the maximum intensity from 6 chews with the molars; chewiness = the number of chews necessary to reduce the sample to consistency ready for swallowing; mealy = the perception of fine, soft particles distributed within the product; fiber awareness = perception of filaments or stands of muscle tissue in product during mastication; and residual connective tissue = judged at swallowing, manipulate on tongue, judging the amount and size of residual fibers. Flavor attributes were defined as follows: beef flavor ID intensity = amount of beef flavor identity in the sample; brown/roasted = a round, full, dark caramelized aromatic generally associated with beef that has been cooked with dry heat; organ meat = aromatics association with cooked organ meat/liver; bloody/serumy = aromatic associated with blood on cooked meat product; metallic = impression of slightly oxidized metal; rancid = aromatic commonly associated with oxidized fat and oils; off-note = aromatic uncharacteristic of the product; sour = basic taste factor of which citric acids in water is typical; salty = fundamental taste factor of which sodium chloride in water is typical; and bitter = fundamental taste factor of which caffeine in water is typical.

[2]Steers finished on pasture or in the feedlot for 138 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 98 d (early finishing), and then on MP, alfalfa (AL), or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON).

[a,b]Means in the same row with uncommon superscripts differ ($P < 0.05$).

Finishing system altered fatty acid composition of the LM and total fatty acid content (Table 6). Total fatty acid content of the LM was 64% less ($P = 0.006$) for FOR than CON. Myrisitic (C14:0) acid concentration was less ($P = 0.011$) and stearic (C18:0) acid concentration greater ($P = 0.007$) for FOR compared with CON. Palmitic acid and overall SFA concentration did not differ ($P > 0.05$) by finishing system or forage species. Pentadecylic (C15:0) acid concentration was greater ($P = 0.045$) for FOR than CON. Margaric acid and total odd-chain fatty acids did not differ ($P > 0.05$) by finishing system or forage species.

Myristoleic and oleic acid concentrations were less ($P = 0.001$) for FOR than CON. Oleic acid concentration and total MUFA of the LM were 21% and 22% less ($P = 0.001$) for FOR than CON. Palmitoleic acid concentrations tended to be less ($P = 0.054$) for FOR than CON. Others (Mitchell et al., 1991; Mandell et al., 1998; Faucitano et al., 2008) also showed greater MUFA and oleic acid concentrations in grain-fed versus grass-fed beef. Duckett et al. (1993) reported that increasing time-on-feed for steers fed concentrate diets resulted in linear increases in MUFA and oleic acid concentration. Comparisons of forage- and concentrate-finished steers have shown that stearoyl-CoA desaturase, the enzyme responsible for the biosynthesis of MUFA, mRNA expression is 46-fold greater in s.c. adipose for concentrate-finished vs. forage-finished steers (Duckett et al., 2009a). Concentrate-finishing enhances oleic acid concentration due to up-regulation of stearoyl-CoA desaturase, the enzyme responsible for the desaturation of stearic to oleic acid.

Trans-10 octadecenoic acid percentage in LM was ninefold greater ($P = 0.004$) for CON than FOR finished. Conversely, trans-11 vaccenic acid (**TVA**) percentage in the LM was 23-fold greater ($P < 0.001$) for FOR than CON. Cis-11 and -12 octadecenoic acid percentages were also greater ($P < 0.05$) for CON than FOR. Concentration of CLA, cis-9 trans-11 isomer, was 146% greater ($P = 0.001$) for FOR than CON. Other isomers of CLA (cis-11, trans-13; *cis*, *cis*; trans, trans) did not differ ($P > 0.05$) due to finishing system. These results are similar to those observed previously for concentrate-finished vs. forage-finished beef (Duckett et al., 2009b).

Forage species grazed before slaughter did not alter transoctadecenoic acids or CLA. In contrast, Schmidt et al. (2012) found increased CLA and trans-11 vaccenic acid concentrations in LM of steers finished on grasses (PM and bermudagrass) than legumes or forbs (AL, chicory, or cowpea) when grazed for longer time periods before slaughter (>115 d). Noci et al. (2005) showed a linear increase in both trans-11 vaccenic acid and CLA, cis-9 trans-11 isomer, with increased grazing days. Thus, our forage species grazing treatments were likely applied for too short of a time period before slaughter to have significant changes on deposition of biohydrogenation intermediates in adipose tissue.

Linoleic (C18:2) acid, arachidonic (C20:4) acid, and total n-6 PUFA concentrations did not differ ($P > 0.05$) by finishing system. Others (Schroeder et al., 1980; Mandell et al., 1998; Noci et al., 2005) have also reported that linoleic acid is not affected by finishing system. Finishing on AL before harvest tended to increase ($P = 0.056$) linoleic acid concentration compared with PM with MP being intermediate. Concentrations of all individual n-3 fatty acids (linolenic acid, EPA, DPA, DHA) and total n-3 fatty acids were greater ($P < 0.001$) for FOR than CON. Finishing on AL increased ($P = 0.017$) linolenic acid compared with MP or PM. Scollan et al. (2006) also reported that finishing on alfalfa increased

Table 6. Least squares means for finishing treatment for LM fatty acid composition[1]

	Forage species					Finishing system			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
No. animals	36	36	24			32	96		
Total fatty acids, g/100g	2.15	2.06	2.25	0.13	0.179	6.08[c]	2.19[d]	0.64	0.006
Fatty acids									
C14:0, %	2.36	2.53	2.40	0.08	0.092	2.76[c]	2.43[d]	0.08	0.011
C14:1, %	0.40	0.45	0.41	0.03	0.372	0.67[c]	0.42[d]	0.03	< 0.001
C15:0, %	0.54	0.53	0.53	0.03	0.978	0.40[d]	0.54[c]	0.05	0.045
C16:0, %	25.01	25.74	25.60	0.40	0.057	26.61	25.38	0.96	0.276
C16:1, %	2.57	2.68	2.78	0.12	0.278	3.64	2.65	0.33	0.054
C17:0, %	1.13	1.09	1.12	0.03	0.506	1.18	1.11	0.07	0.365
C18:0, %	17.02	16.82	16.74	0.56	0.864	13.05[d]	16.88[c]	0.63	0.007
C18:1 trans-10, %	0.18	0.17	0.16	0.07	0.891	1.32[d]	0.14[d]	0.18	0.004
C18:1 trans-11, %	3.58	3.32	3.56	0.20	0.255	0.15[d]	3.48[c]	0.32	< 0.001
C18:1 cis-9, %	32.79	32.29	33.86	0.79	0.245	41.60[c]	32.84[d]	0.48	< 0.001
C18:1 cis-11, %	1.10	1.10	1.09	0.03	0.958	1.57[c]	1.10[d]	0.04	< 0.001
C18:1 cis-12, %	0.14	0.10	0.13	0.03	0.264	0.37[c]	0.13[d]	0.07	0.023
C18:2 n-6, %	2.59	2.85	2.27	0.16	0.056	2.67	2.62	0.17	0.769
C18:2 cis-9 trans-11, %	0.64	0.61	0.70	0.05	0.255	0.26[d]	0.64[c]	0.03	< 0.001
C18:2 cis-11 trans-13, %	0.03	0.03	0.03	0.01	0.800	0.01	0.03	0.02	0.266
C18:2 trans-10 cis-12, %	0.03	0.02	0.03	0.01	0.764	0.01	0.03	0.02	0.423
C18:2 cis, cis, %	0.06	0.05	0.07	0.01	0.562	0.01[d]	0.06[c]	0.01	0.030
C18:2 trans, trans, %	0.22	0.21	0.19	0.03	0.260	0.06	0.21	0.07	0.115
C18:3 n-3, %	1.17[b]	1.32[a]	1.06[b]	0.06	0.017	0.24[d]	1.20[c]	0.05	< 0.001
C20:4 n-6, %	0.87	0.95	0.79	0.14	0.583	0.52	0.91	0.21	0.150
C20:5 n-3, %	0.54	0.60	0.49	0.06	0.277	0.09[d]	0.55[c]	0.03	< 0.001
C22:5 n-3, %	0.85	0.91	0.76	0.07	0.237	0.21[d]	0.85[c]	0.04	< 0.001
C22:6 n-3, %	0.09	0.10	0.07	0.01	0.226	0.03[d]	0.09[c]	0.01	< 0.001
Unidentified, %	6.12[a]	5.60[b]	5.34[b]	0.31	0.049	2.59[d]	5.75[c]	0.63	0.008
Saturated, %	44.45	45.21	44.45	0.54	0.268	42.43	44.74	1.35	0.166
Odd-chain, %	1.65	1.60	1.61	0.09	0.788	1.58	1.64	0.10	0.633
MUFA, %	35.76	35.42	37.05	0.87	0.261	45.91[c]	35.93[d]	0.52	< 0.001
Omega-6 PUFA, %	3.46	3.79	3.08	0.28	0.147	3.18	3.51	0.26	0.286
Omega-3 PUFA, %	2.65	2.92	2.39	0.19	0.110	0.56[d]	2.67[c]	0.14	< 0.001
n-6:n-3 ratio	1.30	1.30	1.29	0.02	0.878	6.01	1.33	0.50	0.001

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON).

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[a,b]For forage finishing treatments, means in the same row with uncommon superscripts differ ($P < 0.05$).

[c,d]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

both linoleic and linolenic acid content. The ratio of n-6 to n-3 fatty acids was greater ($P = 0.001$) for CON than FOR (6.01 vs. 1.33) and did not differ ($P = 0.88$) by forage species. Others (French et al., 2000; Nuernberg et al., 2005; Duckett et al., 2009b) have also reported increased n-3 fatty acids and lower n-6 to n-3 ratio in beef finished on grass instead of concentrates. However, the n-6 to n-3 values reported here for 100% forage-finished beef are lower (1.33 vs. 1.65) than those previously reported by Duckett et al. (2009b) where steers were drylotted and supplemented with hay, soybean hulls and soybean meal to achieve targeted rates of BW gain in the stocker phase before forage-finishing. Noci et al. (2005) reported a linear decrease in n-6 to n-3 ratio as the length of grazing before slaughter increased. Finishing on different forage species for 40 d before slaughter did not alter n-6 to n-3 ratio; however, research has shown that finishing on similar forage species for longer time periods (>115 d) before slaughter can alter the n-6 to n-3 ratio (PM > AL; Schmidt et al., 2012). Health professionals recommend the consumption of diets with an n-6 to n-3 ratio of 4:1 or less (Simopoulos, 2008). McAfee et al. (2011) showed that consumption of grass-fed red meat products increases plasma and platelet n-3 PUFA status. Participants consuming grass-fed red meat had a 32% reduction in plasma n-6:n-3 ratio, whereas concentrate-fed participants had a 56% increase. Both groups of participants consumed the same amount of meat (500 g/wk) for a 4-wk period; however, there were differences in total fat content between the grass-fed and concentrate-fed sources. The grass-fed meat samples (both beef and lamb) had n-6:n-3 ratios of 2.0 compared with concentrate-fed meat samples of 6.1. These ratios are similar to those reported in this study and indicate that lower n-6:n-3 ratios in forage-finished beef can potentially impact human health.

The effect of finishing treatment on proximate composition of the LM is shown in Table 7. Finishing on forages reduced ($P = 0.003$) total lipid content by 61% of the LM compared with CON finished cattle. Similarly, Leheska et al. (2008) reported a 36% reduction in total lipid content of grass-fed versus conventional beef and no difference in protein, ash or cholesterol content. Forage species grazed before harvest did not alter ($P > 0.43$) total lipid content of the LM. Moisture, protein, ash, and cholesterol content of the LM did not differ ($P > 0.25$) between finishing systems or forage species. Williams et al. (1983) found

Table 7. Least squares means for finishing treatment on LM proximate, vitamin and mineral composition[1]

	Forage species					Finishing system			
Variable	MP	AL	PM	SED[2]	*P*-value	CON	FOR	SED[3]	*P*-value
No. animals	36	36	24			32	96		
Proximate composition, g/100g									
Moisture	75.38	75.41	76.32	0.87	0.608	71.81	75.47	2.71	0.249
Protein	20.66	20.51	20.90	0.42	0.465	21.79	20.54	1.02	0.290
Lipid	2.48	2.62	2.74	0.20	0.426	6.71[c]	2.62[d]	0.47	0.003
Ash	1.29	1.27	1.21	0.06	0.506	1.39	1.28	0.23	0.631
Cholesterol, mg/100g	57.20	56.77	56.39	1.02	0.701	57.19	56.90	2.76	0.921
Fat Soluble Vitamins, µg/100g									
α-tocopherol	3.43	2.98	3.43	0.40	0.311	1.40	3.12	0.75	0.086
β-carotene[4]	0.578[a]	0.405[b]	0.519[a]	0.039	0.026	0.057	0.499	0.213	0.173
Minerals									
Calcium, g/100g	0.970	0.935	0.907	0.085	0.701	0.690	0.944	0.145	0.167
Phosphorus, g/100g	16.91	16.83	15.97	0.43	0.177	17.62	16.68	0.531	0.236
Magnesium, g/100g	1.99	1.96	1.88	0.06	0.217	2.11	1.95	0.07	0.116
Potassium, g/100g	30.80	30.87	28.63	0.66	0.061	31.95	30.72	3.14	0.718
Sulfur, g/100g	18.00	18.13	18.18	0.646	0.893	19.75	18.00	19.85	0.427
Sodium, mg/100g	38.57	36.70	36.43	1.01	0.157	39.43[c]	37.34[d]	0.90	0.022
Zinc, mg/100g	3.33	3.34	3.40	0.18	0.924	3.63	3.31	0.39	0.465
Copper, mg/100g	0.056	0.051	0.052	0.007	0.659	0.050	0.052	0.010	0.844
Iron, mg/100g	1.73	1.62	1.70	0.18	0.777	1.581	1.661	0.245	0.762

[1]Steers finished on pasture or in the feedlot for an average of 132 d (overall finishing). Steers on pasture were initially finished on mixed pasture (MP) for 92 d (early finishing), and then on MP, alfalfa (AL) or pearl millet (PM) for the final 40 d (late finishing). Feedlot steers were fed a concentrate ration throughout the finishing period (CON).

[2]Maximum SED among forage finishing treatment means.

[3]SED between concentrate and forage finishing treatment means.

[4]For β-carotene there were 24 observations for each forage finishing treatment.

[a,b]For forage finishing treatments, means in the same row with uncommon superscripts differ ($P < 0.05$).

[c,d]For concentrate vs. forage finishing, means in the same row with uncommon superscripts differ ($P < 0.05$).

decreased total fat content, greater CP, moisture and ash content, and similar cholesterol concentrations in ground soft tissues (including both muscle and external fat) from the front and hind quarter of carcasses from grass-fed compared with grain-fed beef.

The α-tocopherol content of the LM tended (P = 0.086) to be less for CON than FOR. Forage species grazed before harvest did not alter (P = 0.31) α-tocopherol content of the LM. Similarly, others (Yang et al., 2002; Duckett et al., 2009b; Daley et al., 2010) reported greater fat-soluble vitamin contents for pasture-fed than concentrate-fed beef. Li et al. (1995) suggested that the threshold level of muscle α-tocopherol is 3.5 ug/g for extended color and lipid stability. In this study, LM from forage-fed treatments contained on average 3.12 μg/g α-tocopherol, which is slightly below the threshold level. These values for α-tocopherol are lower than previously reportedfor forage-finished vs. concentrate-finished beef in our laboratory (Duckett et al., 2009b). This is due to a change in methodology for α-tocopherol detection as levels are overestimated when ultraviolet instead of fluorescence detection is used due to interfering compounds that elute with α-tocopherol (S. Duckett, unpublished data). β-carotene content of the LM did not differ (P = 0.17) between finishing systems even though numerical differences were observed; however, β-carotene content was greater (P = 0.026) for MP and PM than AL. Dunne et al. (2009) reported strong correlations between s.c. fat color and β-carotene content. However in this study, we did not observe changes in s.c. b* values for steers finished on MP and PM even though differences in β-carotene content were observed. Sodium content was greater (P = 0.022) for CON than FOR. Other minerals (Ca, P, Mg, K, S, Cu, and Fe) did not differ (P > 0.10) by finishing system. Potassium content of LM tended (P = 0.06) to be greater for MP and AL than PM. Other minerals (Ca, P, Mg, Na, S, Cu, and Fe) were unchanged (P > 0.16) with finishing system. Similarly, Duckett et al. (2009b) did not report changes in mineral content of LM with finishing system.

Concentrate finishing increases carcass weight when slaughtering at the same animal age endpoint and accelerates deposition of MUFA. Finishing on forages to similar animal age endpoint produces lighter carcass weights and reduced excess fat deposition but maintains high concentrations of n-3 and CLA fatty acids. Finishing system or forage species grazed 40 d before slaughter did not alter beef tenderness. Steaks from forage-finished steers had greater off-flavors according to both trained and descriptive sensory panelists. Finishing on alternate forage species (AL or PM) just before slaughter did not alter off-flavor scores compared with mixed pasture in this study, which indicates that improved forage varieties can be used in forage-finishing systems without altering carcass quality, tenderness, or flavor.

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