# Effect of muscle type, sire breed, and time of weaning on fatty acid composition of finishing steers[1]

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**ABSTRACT:** Thirty-three steer calves were used to determine the effect of sire breed (Angus or Charolais), time of weaning [normal weaned at approximately 210 d of age (NW) or late weaned at approximately 300 d of age (LW)], and muscle type [LM and semitendinosus muscle (STN)] on fatty acid composition. The whole plot consisted of a 2 (sire breed) × 2 (time of weaning) treatment arrangement, and the subplot treatment was muscle type. Body weights were recorded at 28-d intervals to determine animal performance. Muscle biopsies were collected on d 127 and 128 of finishing. All calves were slaughtered on d 138, and carcass data were collected. Angus-sired steers had lighter initial BW (271 vs. 298 kg; $P = 0.02$), and LW steers were heavier (351 vs. 323 kg; $P = 0.03$) on d 28, but no other differences in BW were noted. Charolais-sired steers had larger LM area ($P = 0.03$), reduced yield grades ($P = 0.01$), less 12th-rib fat ($P < 0.01$), and less marbling ($P < 0.01$) than Angus-sired steers. Carcass measures overall indicate Angus-sired steers were fatter. Hot carcass weight was heavier (348 vs. 324 kg; $P = 0.04$) in LW steers than NW steers. No other differences ($P > 0.05$) were observed for feedlot performance or carcass characteristics. Total lipids were extracted from muscle biopsies, derivatized to their methyl esters, and analyzed using gas chromatography. The LM had greater SFA (43.94 vs. 35.76%; $P < 0.01$) and decreased unsaturated fatty acids (UFA; 56.90 vs. 66.19%; $P < 0.01$) compared with the STN. Percent total MUFA was greater in STN than LM (51.05 vs. 41.98%; $P < 0.01$). Total SFA, UFA, and MUFA did not differ due to sire breed or time of weaning. Total PUFA differed ($P = 0.04$) due to a sire breed × time of weaning interaction but did not differ due to muscle type, with greater PUFA in NW Charolais than any other sire breed × time of weaning combination. Observed changes in percent MUFA may be a result of greater $\Delta^9$-desaturase activity. The calculated desaturase index suggests STN has a greater $\Delta^9$-desaturase activity than LM, but no differences ($P > 0.05$) between sire breed or time of weaning were observed. These results indicate that sire breed, time of weaning, and muscle type all affect fatty acid composition in beef. This information provides insight into factors for manipulation of beef fatty acids. More research is needed to identify beef cuts based on fatty acid profile and healthfulness.

**Key words:** beef, breed, cattle, fatty acid, muscle type, weaning



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## INTRODUCTION

Increasing consumer awareness about the correlation of diet and health has driven research on the manipulation of beef fat composition. Although there is evidence that some beef SFA have negative health effects (Grundy, 1994; Kromhout et al., 1995; Nicolosi et al., 1998), not all SFA in beef are detrimental to health (Berner, 1993; Yu et al., 1995; Judd et al., 2002). In addition, beef contains many beneficially healthy fatty acids: MUFA, PUFA (n-3 and n-6), and CLA (Chin et al., 1992; Hu et al., 1999; Baghurst, 2004; Daley et al., 2010). Research on altering fatty acid composition has focused on the effects of breed (Siebert et al., 1996; Pitchford et al., 2002; Smith et al., 2009a) and diet (Leheska et al., 2008; Alfaia et al., 2009; Duckett et al., 2009). However, there is only limited information on factors such as growth potential (Rule et al., 1997) and nutritional background (Duckett et al., 1993; Noci et al., 2005), and it is not understood how the fatty acid profile differs between different muscle types or how all of these factors interact. The objective of the present

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study was to identify the differences in fatty acid profile of 2 different muscle types from calves sired by breeds of different growth potential and from different weaning programs. Fatty acid profile analysis of the LM (oxidative) and semitendinosus muscle (**STN**; glycolytic; Hunt and Hedrick, 1977) from normal and late-weaned Angus- and Charolais-sired steers were compared. By identifying the natural variation in fatty acid profile of beef from popular production systems, producers could breed and market cattle with enhanced nutritional or health value.

## MATERIALS AND METHODS

All research protocols were approved by the Oklahoma State University Institutional Animal Care and Use Committee.

### *Animals and Diet*

Thirty-three fall-born steer calves selected from the Oklahoma State University Range Cow Research Center, North Range Unit, approximately 16 km west of Stillwater, were used in a split-plot design to evaluate the effects of sire breed (main plot), time of weaning (sub-plot), and muscle type (sub-sub-plot) on fatty acid composition. Steers were the progeny of predominantly Angus cows bred to 1 of 2 sire breeds: Angus or Charolais. Steers were weaned on 1 of 2 dates: normal weaned in mid-April at approximately 210 d of age (**NW**) or late weaned in mid-July at approximately 300 d of age (**LW**). Before and at weaning, calves were managed according to procedures outlined by Hudson et al. (2010a). Postweaning, all steers were managed according to Hudson et al. (2010b). Briefly, steers were weighed after a 16-h withdrawal from feed and water, dewormed based on individual BW with Ivomec Plus (Merial, Duluth, GA), and implanted with Component E-S with Tylan (200 mg of progesterone and 20 mg of estradiol benzoate, Vetlife, Overland Park, KS). Steers were then transported to the Oklahoma State University Willard Sparks Beef Research Center (Stillwater), assigned to pens, and adapted to an 88% concentrate finishing diet (Table 1) over an 18-d period. There were 2 pens of NW Angus with 5 and 6 steers each, 2 pens of LW Angus with 4 steers each, 1 pen of NW Charolais with 6 steers, and 1 pen of LW Charolais with 8 steers. All steers were of similar age, 316 ± 11 d of age, when entering the feedlot. Body weights were recorded at 28-d intervals. On d 56, steers were re-implanted with Revalor-S (120 mg trenbolone acetate and 24 mg of estradiol benzoate, Intervet/Schering-Plough, De Soto, KS). All steers remained on feed for 138 d before slaughter at Tyson Fresh Meats Inc., Emporia, KS. Trained personnel from Oklahoma State University collected carcass data after a 24-h chill that included HCW, marbling score, 12th-rib fat, LM area, and KPH. Yield grade was calculated from HCW, LM area, 12th-rib fat, and KPH. Quality grade was determined from marbling score and maturity data.

**Table 1.** Ingredient and nutrient composition of finishing diet (DM basis)

| Item | % |
|---|---|
| Ingredient | |
| Dry-rolled corn | 67.6 |
| Corn DDGS[1] | 15.7 |
| Ground alfalfa hay | 6.0 |
| Liquid supplement[2] | 5.0 |
| Dry supplement[3] | 5.7 |
| Nutrient composition[4] | |
| DM | 86.60 |
| CP | 13.98 |
| NDF | 16.30 |
| ADF | 7.63 |
| Ca | 0.70 |
| P | 0.43 |

[1]DDGS = distillers dried grains with solubles.

[2]Synergy 19/14 (Westway Feed Products, New Orleans, LA).

[3]Pelleted supplement contained the following (DM basis): 40.35% ground corn, 19.73% wheat middlings, 21.42% limestone, 4.39% dicalcium phosphate, 5.79% salt, 0.05% manganous oxide, 1.14% available zinc 100, 0.07% zinc sulfate, 4.56% potassium chloride, 1.93% magnesium oxide, 0.06% vitamin A (30,000 IU/g), 0.04% vitamin E (50%), 0.31% Rumensin 80 (Elanco Animal Health, Indianapolis, IN), and 0.17% Tylan 40 (Elanco Animal Health).

[4]All values are from laboratory analyses and are presented on a 100% DM basis (except DM).

### *Tissue Collection*

Biopsies of the LM and STN were collected from all steers on d 127 and 128 of the finishing phase. Briefly, steers were restrained in a hydraulic squeeze chute, hair was removed from both biopsy sites, and a local anesthetic (lidocaine HCl, 20 mg/mL, 10 mL/biopsy) was administered. The biopsy sites were surgically scrubbed with a commercially available iodine solution (Betadine Surgical Scrub, Purdue Products, Stamford, CT) followed by a rinse with 70% isopropyl alcohol solution. Using a scalpel, a 1-cm incision was made between the 10th and 13th ribs, and a sterile Bergstrom biopsy needle was used to obtain approximately a 1-g sample of LM (Dunn et al., 2003; Pampusch et al., 2003). A second 1-cm incision was made adjacent to the pin bone and approximately 5 cm lateral to the tail to collect approximately a 1-g sample of STN according to Ledwith and McGowan (2004). All steers were monitored for swelling during the 24-h postbiopsy period.

### *Fatty Acid Extraction, Derivatization, and Gas Chromatography Analysis*

Measurements of fatty acids (% composition) were made in triplicate using approximately 65 mg of the LM and STN biopsy samples from all steers using the chloroform methanol lipid extraction method described by Bligh and Dyer (1959). Briefly, tissue samples were

homogenized by hand using glass/glass Tenbroeck homogenizers in 3.0 mL of methanol:chloroform (2:1, vol/vol) solution, and lipids were extracted according to Bligh and Dyer (1959). Lipid extracts were stored at −20°C in chloroform containing 0.5% (wt/vol) butylated hydroxytoluene. Extracted lipids were converted to methyl esters with sodium methylate (0.5 *M*) to reduce CLA isomerization and boron trifluoride in methanol (14%, wt/vol) to derivatize all FFA, according to the procedures of Nuernberg et al. (2002). Fatty acid methyl esters (**FAME**) were redissolved in hexane and loaded on silica gel columns for further purification before analysis. A 5% ether in hexane solution was used to elute the FAME, which were then analyzed by gas chromatography on an Agilent 5890 gas chromatograph with 7673 auto sampler (Agilent Technologies, Wilmington, DE). The FAME were introduced onto a (50% Cyanopropyl)-methylpolysiloxane DB-23 column 30 m × 0.20 mm with a 0.25-μm film thickness (J&W Scientific, Folsom, CA) using a split injector set at 250°C with a 1:25 split ratio. Ultrapure helium was the carrier gas at 1 mL/min, and the gas chromatograph program was as follows: 115°C for 1 min, 20°C/min to 175°C, 0.8°C/min to 185°C, and 10°C/min to 225°C for 3 min for a total run time of 23.50 min. A flame ionization detector (Agilent Technologies, Wilmington, DE), operating at 300°C, was used, and peak areas were recorded by HP-Chemstation software. Fatty acid methyl esters were identified by comparison of retention times with authentic standards (Nu-Chek Prep Inc., Elysian, MN).

All fatty acid components were used to calculate total percentage of SFA, MUFA, PUFA, n-3 PUFA, and n-6 PUFA. A total desaturase index was calculated as a ratio of the $\Delta^9$-desaturase products (total MUFA plus 18:2*cis*-9,*trans*-11) divided by the sum of the $\Delta^9$-desaturase products and substrates (total SFA plus 18:1*trans*), as described by Kelsey et al. (2003) and Smith et al. (2006).

### *Statistical Analysis*

Animal performance and carcass data were analyzed as a completely randomized design in a 2 × 2 factorial arrangement of treatments (sire breed = Angus vs. Charolais; time of weaning = NW vs. LW) using the MIXED procedure (SAS Inst. Inc., Cary, NC). Steer was considered the experimental unit. The model statement contained fixed effects of sire breed and time of weaning. The random statement included pen. Because there were unequal numbers of steers per treatment group (n = 11 for Angus × NW, n = 8 for Angus × LW, n = 6 for Charolais × NW, and n = 8 for Charolais × LW), the Satterthwaite denominator degrees of freedom were specified. Least squares means were separated using the PDIFF option of SAS. Treatments were determined to be different at $\alpha = 0.05$.

Fatty acid data were analyzed as a split-plot design using the MIXED procedure of SAS. The whole plot (steer) had a 2 (sire breed) × 2 (time of weaning) treatment arrangement, and the subplot treatment was muscle type (LM vs. STN). Steer was considered the experimental unit. The model statement contained fixed effects of sire breed, time of weaning, and muscle type. The random statement included time of breed × time of weaning × pen and steer nested within breed × time of weaning × pen. Least squares means were separated using the PDIFF option of SAS. Treatments were determined to be different at $\alpha = 0.05$.

## RESULTS

### *Animal Performance and Carcass Characteristics*

There were no sire breed × time of weaning interactions for feedlot performance throughout the finishing period; therefore, only main effects are reported in Table 2. On arrival at the feedlot (d 0), Charolais-sired steers were heavier (298 vs. 271 kg; $P = 0.02$) than Angus-sired steers. On d 28, LW steers were heavier (351 vs. 323 kg; $P = 0.03$) than NW steers. Final BW tended to be greater in LW steers, but overall ADG did not differ due to sire breed or time of weaning. There were no other differences for BW or ADG due to sire breed or time of weaning throughout the finishing period.

There were no sire breed × time of weaning interactions for carcass characteristics; main effects are shown in Table 3. There were no differences in HCW ($P = 0.84$) or DP ($P = 0.71$) due to sire breed. Hot carcass weight was greater (348 vs. 324 kg; $P = 0.04$) for LW than NW steers, and DP tended to be greater in LW than NW steers. Charolais-sired steers, regardless of time of weaning, had greater LM area ($P = 0.03$), less 12th-rib fat ($P < 0.01$), reduced yield grades ($P = 0.01$), and decreased marbling scores ($P < 0.01$) compared with Angus-sired steers. There were no other observed differences in carcass characteristics due to treatment or treatment interactions.

### *Fatty Acid Analysis*

The sire breed × time of weaning × muscle type interactions for fatty acid composition in finishing beef steers are shown in Table 4.

***SFA.*** Percent total SFA was similar between sire breeds and weaning dates; however, the STN had a smaller (35.76 vs. 43.94; $P < 0.01$) percent SFA compared with the LM. Specifically, capric acid (10:0), lauric acid (12:0), palmitic acid (16:0), and stearic acid (18:0) were less ($P < 0.01$) in the STN than the LM. In contrast, percent pentadecanoic acid (15:0) was greater ($P = 0.01$) in the STN than the LM. There was a sire breed × time of weaning × muscle type interaction for myristic acid (14:0). The STN from LW Angus had the greatest (3.07; $P = 0.04$) percent 14:0 and the LM from NW Charolais had the least (1.85; $P = 0.04$) percent 14:0, with all other treatment groups being intermediate and similar.

**Table 2.** Effect of sire breed and time of weaning on feedlot performance of beef steers[1]

| | Sire breed (B) | | | Time of weaning (W) | | | *P*-value[3] | |
|---|---|---|---|---|---|---|---|---|
| Item | Angus | Charolais | SEM[2] | NW | LW | SEM[2] | B | W |
| BW, kg | | | | | | | | |
| d 0 | 271 | 298 | 9 | 274 | 296 | 8 | 0.02 | 0.06 |
| d 28 | 328 | 345 | 9 | 323 | 351 | 9 | 0.17 | 0.03 |
| d 56 | 377 | 391 | 10 | 374 | 395 | 9 | 0.27 | 0.11 |
| d 84 | 444 | 448 | 11 | 430 | 461 | 11 | 0.80 | 0.06 |
| d 112 | 490 | 500 | 14 | 482 | 508 | 13 | 0.64 | 0.30 |
| Final | 540 | 541 | 13 | 525 | 557 | 12 | 0.92 | 0.08 |
| ADG, kg/d | | | | | | | | |
| 0 to 28 d | 2.03 | 1.68 | 0.22 | 1.75 | 1.96 | 0.20 | 0.36 | 0.54 |
| 29 to 56 d | 1.75 | 1.64 | 0.11 | 1.83 | 1.57 | 0.10 | 0.58 | 0.32 |
| 57 to 84 d | 2.38 | 2.01 | 0.13 | 2.02 | 2.36 | 0.13 | 0.06 | 0.06 |
| 85 to 112 d | 1.65 | 1.87 | 0.27 | 1.84 | 1.68 | 0.24 | 0.59 | 0.70 |
| 113 d to end | 1.92 | 1.59 | 0.34 | 1.65 | 1.86 | 0.30 | 0.53 | 0.67 |
| 0 d to end | 1.94 | 1.76 | 0.07 | 1.82 | 1.89 | 0.06 | 0.23 | 0.54 |

[1]NW = normal weaned in mid-April at approximately 210 d of age; LW = late weaned in mid-July at approximately 300 d of age.
[2]SEM of the least squares means (n = 19 steers for Angus; n = 14 steers for Charolais; n = 17 steers for NW; n = 16 steers for LW).
[3]Observed significance levels for main effects.

***Unsaturated Fatty Acids.*** Percent total unsaturated fatty acids (**UFA**) differed due to muscle type but not sire breed or time of weaning. The STN had a greater (66.19 vs. 56.90; $P < 0.01$) percent UFA compared with the LM. The UFA:SFA ratio was greater (1.87 vs. 1.30; $P < 0.01$) in the STN than the LM but did not differ due to sire breed or time of weaning.

***MUFA.*** There were no significant 3-way or 2-way treatment interactions for MUFA, but percent total MUFA differed for all main effects. Percent MUFA was greater (51.05 vs. 41.95; $P < 0.01$) in STN than LM. Individual MUFA myristolic acid (14:1), palmitoleic acid (16:1), hepadecanoic acid (17:1), and oleic acid (18:1 *cis*) were greater ($P < 0.01$) in STN than in LM. Percent total MUFA was greater (49.05 vs. 43.95; $P = 0.01$) in Angus-sired steers than Charolais-sired steers. Later-weaned steers had a greater (49.02 vs. 43.98; $P = 0.01$) percent MUFA than NW steers. The MUFA:SFA ratio was greater (1.41 vs. 0.95; $P < 0.01$) in STN than LM.

***PUFA.*** There was a sire breed × time of weaning interaction for percent total PUFA, with the NW Charolais steers having a greater ($P = 0.04$) percent PUFA than all other treatment groups. Muscle type did not affect percent total PUFA. There was a sire breed × time of weaning × muscle type interaction ($P \leq 0.02$) for percent total n-6 and n-3 PUFA. Individual PUFA, linoleic acid (18:2n-6), α-linoleic acid (18:3n-3), 20:2n-6, 20:3n-6, arachidonic acid (20:4n-6), and eicosapentaenoic acid (**EPA**; 20:5n-3) all had significant ($P \leq 0.03$) sire breed × time of weaning × muscle type interactions. The PUFA:SFA ratio was greater (0.47 vs. 0.34; $P = 0.04$) in Charolais-sired steers than Angus-sired steers and also greater (0.48 vs. 0.33; $P = 0.02$) in NW than LW steers. The n-6:n-3 ratio was not affected by sire breed but was less (15.58 vs. 18.33; $P < 0.01$) in LW than NW steers and less (13.45 vs. 20.46; $P < 0.01$) in STN than LM. Percent total CLA did not differ due to sire breed, time of weaning, muscle type, or their interaction.

**Table 3.** Effect of sire breed × time of weaning on carcass characteristics of finishing beef steers[1]

| | Sire breed (B) | | | Time of weaning (W) | | | *P*-value[3] | |
|---|---|---|---|---|---|---|---|---|
| Item | Angus | Charolais | SEM[2] | NW | LW | SEM[2] | B | W |
| HCW, kg | 335 | 337 | 9 | 324 | 348 | 8 | 0.84 | 0.04 |
| Dressing percent | 62.0 | 62.2 | 0.4 | 61.6 | 62.6 | 0.4 | 0.71 | 0.07 |
| LM area, $cm^2$ | 79.74 | 85.98 | 2.13 | 81.12 | 84.60 | 2.00 | 0.03 | 0.23 |
| 12th-rib fat, cm | 1.11 | 0.72 | 0.10 | 0.81 | 1.02 | 0.09 | <0.01 | 0.12 |
| KPH, % | 2.61 | 2.29 | 0.24 | 2.38 | 2.53 | 0.23 | 0.32 | 0.63 |
| Yield grade | 2.87 | 2.23 | 0.16 | 2.43 | 2.68 | 0.15 | 0.01 | 0.26 |
| Marbling score[4] | 472 | 408 | 17 | 424 | 456 | 16 | <0.01 | 0.16 |

[1]NW = normal weaned in mid-April at approximately 210 d of age; LW = late weaned in mid-July at approximately 300 d of age.
[2]SEM of the least squares means (n = 19 steers for Angus; n = 14 steers for Charolais; n = 17 steers for NW; n = 16 steers for LW).
[3]Observed significance levels for main effects.
[4]Marbling score units: 400 = small[00]; 500 = modest[00].

**Table 4.** Sire breed × time of weaning × muscle type interaction for fatty acid composition in finishing beef steers[1,2]

| | Angus | | | | Charolais | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NW | | LW | | NW | | LW | | | *P*-value[5] | | | | | | |
| Item[3] | LM | STN | LM | STN | LM | STN | LM | STN | SEM[4] | B | W | M | B × W | B × M | W × M | B × W × M |
| Fatty acid, % | | | | | | | | | | | | | | | | |
| 10:0 | 0.03 | 0.01 | 0.04 | 0.02 | 0.06 | 0.02 | 0.02 | 0.01 | 0.01 | 0.54 | 0.31 | <0.01 | 0.09 | 0.56 | 0.18 | 0.29 |
| 12:0 | 0.19 | 0.05 | 0.12 | 0.07 | 0.26 | 0.08 | 0.13 | 0.06 | 0.05 | 0.39 | 0.11 | <0.01 | 0.42 | 0.71 | 0.08 | 0.84 |
| 14:0 | $2.79^{ab}$ | $2.13^{ab}$ | $2.91^{ab}$ | $3.07^{a}$ | $1.85^{b}$ | $2.57^{ab}$ | $2.99^{ab}$ | $2.30^{ab}$ | 0.44 | 0.27 | 0.08 | 0.65 | 0.86 | 0.63 | 0.59 | 0.04 |
| 14:1 | 0.57 | 0.84 | 0.62 | 1.07 | 0.27 | 0.95 | 0.69 | 0.99 | 0.18 | 0.65 | 0.10 | <0.01 | 0.67 | 0.58 | 0.66 | 0.21 |
| 15:0 | 0.48 | 0.59 | 0.53 | 0.83 | 0.45 | 0.62 | 0.51 | 0.54 | 0.09 | 0.19 | 0.24 | 0.01 | 0.18 | 0.35 | 0.87 | 0.15 |
| 16:0 | 26.04 | 22.31 | 26.15 | 20.25 | 24.19 | 23.11 | 25.87 | 23.35 | 1.74 | 0.76 | 1.00 | <0.01 | 0.55 | 0.14 | 0.37 | 0.86 |
| 16:1 | 3.10 | 4.76 | 2.91 | 4.93 | 2.08 | 5.26 | 2.95 | 5.00 | 0.59 | 0.85 | 0.79 | <0.01 | 0.77 | 0.11 | 0.42 | 0.13 |
| 17:0 | 1.30 | 1.36 | 1.43 | 2.14 | 1.11 | 1.39 | 1.30 | 1.21 | 0.36 | 0.41 | 0.50 | 0.23 | 0.50 | 0.46 | 0.72 | 0.19 |
| 17:1 | 0.99 | 1.58 | 0.89 | 2.38 | 0.73 | 1.60 | 0.86 | 1.36 | 0.29 | 0.10 | 0.44 | <0.01 | 0.30 | 0.29 | 0.44 | 0.07 |
| 18:0 | 13.50 | 8.88 | 13.82 | 7.91 | 13.51 | 8.33 | 14.15 | 8.79 | 0.60 | 0.69 | 0.78 | <0.01 | 0.30 | 0.99 | 0.27 | 0.40 |
| 18:1 *cis* | 37.37 | 42.20 | 37.21 | 44.22 | 29.14 | 36.44 | 37.52 | 40.94 | 3.04 | 0.22 | 0.27 | <0.01 | 0.37 | 0.83 | 0.74 | 0.24 |
| 18:1 *trans* | 1.55 | 1.28 | 2.03 | 2.94 | 1.16 | 1.74 | 2.15 | 1.55 | 0.95 | 0.73 | 0.44 | 0.69 | 0.70 | 0.68 | 1.00 | 0.14 |
| 18:2 *trans trans* | 0.19 | 0.44 | 0.24 | 0.49 | 0.14 | 0.12 | 0.24 | 0.47 | 1.11 | 0.19 | 0.21 | 0.09 | 0.19 | 0.18 | 0.18 | 0.18 |
| 18:2n-6 | $8.60^{b}$ | $9.05^{b}$ | $8.09^{b}$ | $7.56^{b}$ | $17.54^{a}$ | $7.62^{b}$ | $7.63^{b}$ | $8.58^{b}$ | 1.81 | 0.27 | 0.18 | 0.01 | 0.33 | 0.02 | 0.01 | <0.01 |
| 18:2 *cis*-9,*trans*-11 | 0.21 | 0.28 | 0.32 | 0.55 | 0.29 | 2.54 | 0.32 | 0.41 | 0.66 | 0.18 | 0.29 | 0.11 | 0.13 | 0.22 | 0.22 | 0.16 |
| 18:2 *trans*-10,*cis*-12 | 0.02 | 0.06 | 0.03 | 0.06 | 0.08 | 0.06 | 0.03 | 0.07 | 0.03 | 0.24 | 0.58 | 0.27 | 0.51 | 0.40 | 0.45 | 0.33 |
| 18:3n-3 | $0.29^{ab}$ | $0.38^{ab}$ | $0.31^{ab}$ | $0.40^{ab}$ | $0.52^{ab}$ | $0.39^{ab}$ | $0.30^{b}$ | $0.44^{a}$ | 0.07 | 0.31 | 0.58 | 0.09 | 0.42 | 0.14 | 0.03 | 0.03 |
| 20:2n-6 | $0.12^{cd}$ | $0.18^{abe}$ | $0.11^{de}$ | $0.17^{bc}$ | $0.29^{a}$ | $0.17^{bcd}$ | $0.12^{bcd}$ | $0.18^{abcd}$ | 0.03 | 0.20 | 0.23 | 0.33 | 0.30 | 0.01 | 0.01 | 0.01 |
| 20:3n-6 | $0.54^{b}$ | $0.75^{ab}$ | $0.43^{b}$ | $0.58^{b}$ | $1.25^{a}$ | $0.61^{b}$ | $0.51^{ab}$ | $0.71^{ab}$ | 0.19 | 0.31 | 0.25 | 0.77 | 0.59 | 0.02 | 0.03 | 0.01 |
| 20:4n-6 | $1.89^{cd}$ | $3.27^{ab}$ | $1.55^{bd}$ | $2.36^{abc}$ | $4.54^{ac}$ | $2.33^{bd}$ | $1.71^{abc}$ | $3.08^{abc}$ | 0.86 | 0.43 | 0.33 | 0.38 | 0.78 | 0.05 | 0.05 | 0.01 |
| 20:5n-3 | $0.23^{bd}$ | $0.51^{ac}$ | $0.29^{abc}$ | $0.44^{abc}$ | $0.51^{abc}$ | $0.46^{abc}$ | $0.20^{cd}$ | $0.69^{ab}$ | 0.14 | 0.42 | 0.84 | <0.01 | 0.87 | 0.99 | 0.15 | 0.02 |
| 22:1 | $0.11^{b}$ | $0.01^{c}$ | $0.11^{b}$ | $0.01^{c}$ | $0.27^{a}$ | $0.03^{c}$ | $0.09^{b}$ | $0.01^{c}$ | 0.02 | <0.01 | <0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 |
| Sum, % | | | | | | | | | | | | | | | | |
| SFA | 44.33 | 35.32 | 45.00 | 35.32 | 41.44 | 36.12 | 44.98 | 36.27 | 1.27 | 0.73 | 0.21 | <0.01 | 0.38 | 0.12 | 0.18 | 0.36 |
| UFA | 56.57 | 66.28 | 55.65 | 68.89 | 59.18 | 64.63 | 56.21 | 64.97 | 1.87 | 0.63 | 0.85 | <0.01 | 0.38 | 0.06 | 0.13 | 0.96 |
| MUFA | 44.36 | 51.24 | 44.30 | 56.29 | 34.01 | 46.31 | 45.12 | 50.37 | 2.53 | 0.01 | 0.01 | <0.01 | 0.16 | 0.85 | 0.79 | 0.10 |
| PUFA | $12.21^{y}$ | $15.03^{y}$ | $11.36^{y}$ | $12.60^{y}$ | $25.17^{x}$ | $18.31^{x}$ | $11.09^{y}$ | $14.61^{y}$ | 2.43 | 0.01 | <0.01 | 0.92 | 0.04 | 0.29 | 0.21 | 0.09 |
| n-6 | $11.15^{b}$ | $13.24^{b}$ | $10.18^{b}$ | $10.66^{b}$ | $23.63^{a}$ | $10.74^{b}$ | $9.98^{b}$ | $12.54^{ab}$ | 2.88 | 0.31 | 0.22 | 0.16 | 0.44 | 0.02 | 0.01 | <0.01 |
| n-3 | $0.52^{bd}$ | $0.89^{ac}$ | $0.59^{abc}$ | $0.84^{abc}$ | $1.03^{abc}$ | $0.85^{abc}$ | $0.51^{cd}$ | $1.13^{ab}$ | 0.19 | 0.35 | 0.72 | 0.01 | 0.66 | 0.64 | 0.08 | 0.02 |
| CLA | 0.23 | 0.34 | 0.34 | 0.61 | 0.37 | 0.60 | 0.36 | 0.47 | 0.66 | 0.17 | 0.29 | 0.10 | 0.13 | 0.23 | 0.24 | 0.17 |
| Ratio | | | | | | | | | | | | | | | | |
| UFA:SFA | 1.28 | 1.91 | 1.24 | 1.87 | 1.44 | 1.87 | 1.25 | 1.81 | 0.11 | 0.86 | 0.29 | <0.01 | 0.58 | 0.28 | 0.64 | 0.64 |
| MUFA:SFA | 1.01 | 1.49 | 0.98 | 1.49 | 0.82 | 1.28 | 1.00 | 1.39 | 0.11 | 0.30 | 0.51 | <0.01 | 0.46 | 0.52 | 0.84 | 0.64 |
| PUFA:SFA | 0.28 | 0.43 | 0.26 | 0.38 | 0.62 | 0.59 | 0.25 | 0.42 | 0.09 | 0.04 | 0.02 | 0.10 | 0.24 | 0.56 | 0.50 | 0.36 |
| n-6:n-3 | 21.21 | 15.37 | 18.27 | 12.79 | 22.91 | 13.82 | 19.46 | 11.82 | 1.36 | 0.92 | <0.01 | <0.01 | 0.99 | 0.08 | 0.54 | 0.71 |
| DI[6] | <0.01 | 0.58 | <0.01 | 0.59 | <0.01 | 0.56 | <0.01 | 0.57 | 0.02 | 0.64 | 0.86 | <0.01 | 0.97 | 0.26 | 0.61 | 0.99 |

[a–e]Within a row, least squares means without a common superscript differ ($P \leq 0.05$) for the B × W × M interaction.

[x,y]Within a row, least squares means without a common superscript differ ($P \leq 0.05$) for the B × W interaction.

[1]NW = normal weaned in mid-April at approximately 210 d of age; LW = late weaned in mid-July at approximately 300 d of age.

[2]STN = semitendinosus muscle.

[3]SFA = (10:0 + 12:0 + 14:0 + 15:0 + 16:0 + 17:0 + 18:0); UFA = unsaturated fatty acids (MUFA + PUFA); MUFA = (14:1 + 16:1 + 17:1 + 18:1 + 22:1); PUFA = (18:2 *trans, trans* + 18:2n-6 + 18:2 *cis*-9,*trans*-11 + 18:2 *trans*-10,*cis*-12 + 18:3n-3 + 20:2 + 20:3n-6 + 20:4n-6 + 20:5n-3); n-6 = n-6 fatty acids (18:2n-6 + 20:2n-6 + 20:3n-6 + 20:4n-6); n-3 = n-3 fatty acids (18:3n-3 + 20:5n-3); CLA = (18:2 *cis*-9,*trans*-11 + 18:2 *trans*-10,*cis*-12).

[4]SEM of the least squares means (n = 11 for Angus × NW × LM and Angus × NW × STN; n = 8 for Angus × LW × LM and Angus × LW × STN; n = 6 for Charolais × NW × LM and Charolais × NW × STN; n = 8 for Charolais × LW × LM and Charolais × LW × STN).

[5]Observed significance levels for the main effects (B = sire breed; W = time of weaning; M = muscle type) and their 2- and 3-way interactions.

[6]DI = desaturase index calculated as a ratio of the $\Delta^9$-desaturase product divided by the sum of the $\Delta^9$-desaturase product and substrate ([total MUFA + 18:2 *cis*-9,*trans*-11]/[total MUFA + 18:2 *cis*-9,*trans*-11 + total SFA + 18:1 *trans*]).

***Desaturase Index.*** The $\Delta^9$-desaturase index was greater ($P < 0.01$) in STN than in LM. This would be an indication of a greater $\Delta^9$-desaturase activity in the STN than the LM. There were no differences indicated by the desaturase index for $\Delta^9$-desaturase activity between sire breeds or times of weaning.

## DISCUSSION

Consumers are becoming more aware of the relationship between diet and health, and this has increased consumer interest in the nutritional value of foods. Health professionals recommend a reduction in the overall consumption of SFA, while emphasizing the need to increase intake of n-3 PUFA (Griel and Kris-Etherton et al., 2006). This recommendation is based on a positive correlation between diets rich in SFA and atherosclerosis and other vascular diseases (Keys et al., 1957; Hegsted et al., 1965). The amount of SFA (38%) in beef is less than the total amount of UFA in the form of MUFA (42%) and PUFA (3 to 5%) on a per edible portion basis (Baghurst, 2004; NCBA, 2008). The predominant SFA are palmitic acid (16:0) and stearic acid (18:0). Stearic acid has a neutral effect on serum cholesterol concentration (Zock and Katan, 1992; Kris-Etherton et al., 1993; Judd et al., 2002). Palmitic acid has a cholesterol-raising effect, but has a less potent influence on cholesterol concentration than the shorter chain SFA (Zock et al., 1994). Lauric (12:0) and myristic (14:0) fatty acids are responsible for increasing the serum LDL cholesterol concentration (Grundy, 1994), but account for only 1% and 2 to 3% of SFA in beef, respectively. Beef also contains fatty acids that have beneficial health effects (e.g., n-3 PUFA and CLA). Both n-3 PUFA and CLA are present in much smaller quantities compared with the other fatty acid classes; however, lipids of ruminant origin are among the richest sources of CLA (Chin et al., 1992).

Selection of beef cattle breeds or combinations of breeds has been traditionally based on growth performance, intended market, climatic adaptability, and personal preference rather than on the nutritional value of meat produced. Differences in fatty acid composition among breeds has been related to total amount of fat in the carcass (Harper and Pethick, 2004; Scollan et al., 2006). However, De Smet et al. (2004) suggested a possible genetic variation in the fatty acid metabolism among breed that alters fatty acid composition. Data reported by Smith et al. (2009a) establish differences between muscle and adipose tissue lipids among Brahman, Hereford, Angus, Australian crossbred, Japanese Black, and Hanwoo steers, suggesting that breeds of cattle differ in their ability to accumulate MUFA. Several breed comparisons have shown Charolais cattle to have a greater concentration of SFA and decreased concentration of MUFA compared with Angus, Simmental, and Hereford cattle (Bures et al., 2006; Barton et al., 2008). The effect of breed on intramuscular fatty acid composition appears to be limited to changes in SFA and MUFA concentrations. Other factors, like muscle type and time of weaning, could have an effect on fatty acid composition, and knowledge of these factors could be used by producers to market cattle or different cuts of meat with enhanced health value.

### *Animal Performance and Carcass Characteristics*

In the present study, growing Angus- and Charolais-sired steers were used to determine if sire breed, time of weaning, or muscle type had an effect on fatty acid composition. All steers were of similar age, were fed the same diet, and were exposed to the same environmental elements to minimize nontreatment effects. The overall design of this study allowed evaluation of sire breed, time of weaning, and muscle type effects on fatty acid composition of products representative of a typical production system. It is clear that tissue fatty acid composition is correlated with tissue fatness (De Smet et al., 2004), and previous research focused on comparing fatty acid composition at a constant backfat thickness to eliminate the bias caused by total fat content the tissue. However, it is important to estimate the fatty acid composition of cattle from a typical production system for each breed and how this composition varies within common production systems. Our results are consistent with previous studies comparing British breeds such as Angus with Continental breeds such as Charolais, where British breeds were generally smaller in mature size, earlier maturing, and produced carcasses with more fat and a smaller percentage of lean muscle (Peacock et al., 1982; Coleman et al., 1993; Arango et al., 2002). Moreover, our data suggest that in a fall-calving beef production system, producers could use late weaning without compromising (Charolais) or improving (Angus) carcass characteristics, in particular marbling.

### *Fatty Acid Composition*

***Muscle Type Effect.*** Several differences in fatty acid composition were observed between the LM and the STN. A characteristic of skeletal muscle is its diversity, consisting of different types of muscle fibers that have different structural and functional properties (Pette and Staron, 1990). Schreurs et al. (2008) indicated that muscle type accounts for the largest portion of the variation in muscle characteristics including those that affect meat quality. The 2 skeletal muscles analyzed in this study vary widely in muscle characteristics including muscle fiber type. Jurie et al. (2006) showed that the STN had a greater percentage of fast-twitch glycolytic fibers, whereas the LM had a greater percentage of slow-twitch oxidative fibers. Muscle fiber types are dynamic, constantly changing in proportion as the animal ages, but muscle type is a reflection of the energy requirements of the muscle (Hocquette et al., 1998; Oddy et al., 2001). Because the STN is involved in animal movement, it may have a greater energy re-

quirement than the LM, which results in the STN having a greater proportion of glycolytic enzymatic activity. Literature has also shown that changes in fatty acid composition within muscle are associated with changes in proportions of muscle fiber types (Jurie et al., 2005; Von Seggern et al., 2005; Alfaia et al., 2007), and it has been well established that the lipid content is greater in oxidative muscle fibers (Alasnier et al., 1996; Enser et al., 1998). In the present study, STN had a reduced percentage of SFA, greater percentage of MUFA, and no significant differences in the percentage of PUFA compared with the LM. Our data show a greater UFA-to-SFA ratio in the STN than the LM, but also a difference between STN and LM in their ability to accumulate MUFA vs. PUFA. The STN had a greater MUFA-to-SFA ratio than the LM and tended to have a decreased PUFA-to-SFA ratio. This could be the result of a greater $\Delta^9$-desaturase activity in the STN than the LM as indicated by the calculated desaturase indices. Similarly, Alfaia et al. (2007) demonstrated that the LM had a greater amount of SFA but a decreased proportion of UFA compared with the STN.

These results suggest that various cuts of meat from the same sire breed have different fatty acid profiles and therefore different value with respect to their impact on human health; however, total fat content in addition to fatty acid profile must be considered. Most of the present literature focuses solely on fatty acid composition of the LM under different feeding and growing conditions and from a variety of breeds, and more research is needed on the effect of these experimental conditions on other muscles. Knowledge of fatty acid composition of different cuts of meat from various breeds under current production systems could lead to marketing strategies that emphasize the healthfulness value. This could provide health benefits to a large range of consumers without a dramatic change in dietary habits.

***Breed Effect.*** Fat in beef can be present in several adipose tissue depots: cell membrane, intermuscular (seam fat), intramuscular (marbling), and subcutaneous. Research on breed effects on fatty acid composition of beef has focused heavily on subcutaneous adipose tissue. Differences in fatty acid composition of subcutaneous adipose have been reported for Brahman and Hereford (Huerta-Leidenz et al., 1993), Hereford crossbreds (Siebert et al., 1996; Pitchford et al., 2002), and Limousin and Jersey (Malau-Aduli et al., 1997) cattle. However, there is less information regarding the effect of breed on fatty acid composition of marbling in beef. From a human health standpoint, analyzing marbling adipose may be more important because subcutaneous adipose is trimmed before human consumption.

The results presented in this study show Angus-sired steers had a greater percentage of total MUFA compared with Charolais-sired steers. This is in agreement with data compiled by Smith et al. (2009a) suggesting breeds of cattle differ in their ability to accumulate MUFA in adipose tissues. This is also supported by findings from Johnson (1987) and Oka et al. (2002), which suggest steers from greater-growth-potential or later-maturing sires may have a decreased percentage MUFA compared with steers from early maturing sires in their subcutaneous or intramuscular fat depots (or both). Percent MUFA has also been shown to increase with increasing marbling and time on feed, which may be associated with an increase in $\Delta^9$-desaturase activity (Chung et al., 2006; Smith et al., 2006, 2009b). Desaturase indices more accurately estimate the $\Delta^9$-desaturase activity compared with total MUFA percentage because they account for changes in substrate and product. The ratio of palmitoleic acid (16:1) to stearic acid (18:0) has been shown to be highly correlated ($R^2 = 0.93$; Chung et al., 2007) with $\Delta^9$-desaturase activity in cattle fed high-corn diets. However, there are limitations to this correlation, which may not hold true when comparing diets that vary widely in fatty acid composition (Archibeque et al., 2005). The total $\Delta^9$-desaturase index calculated using data from the present study would indicate the $\Delta^9$-desaturase activity was similar between the Angus- and Charolais-sired steers. Therefore, the greater percent MUFA observed in the Angus-sired steers may not be due to a greater $\Delta^9$-desaturase activity attributable to greater stearoyl-CoA desaturase gene expression.

Angus-sired steers had a reduced ($P = 0.04$; Table 4) PUFA-to-SFA ratio compared with the Charolais-sired steers. This could be caused by a greater marbling-to-lean ratio and perhaps a greater triacylglyceride-to-phospholipid ratio in the Angus-sired steers compared with the Charolais-sired steers. Triacylglycerides are the primary components of marbling, whereas phospholipids are structural and make up the lean muscle cell membrane. Cell membrane phospholipids in LM of steers contain 34 to 40% SFA, 25 to 27% MUFA, and 34 to 36% PUFA, whereas triacylglycerides contain 39 to 47% SFA, 50 to 58% MUFA, and only 2 to 3% PUFA (Hornstein et al., 1967; Manner et al., 1984; Zembayashi et al., 1995). Therefore, phospholipids are a significant source of PUFA in muscle and are related to the amount of marbling deposition. Siebert et al. (1996) also showed a shift in PUFA in crossbred steers, which he attributed to greater content of membrane phospholipids in later-maturing cattle.

***Time of Weaning Effect.*** Normal-weaned steers, regardless of sire breed, had greater PUFA-to-SFA ratios and a decreased percent total MUFA compared with LW steers. This is likely due to differences in carcass leanness as a result of differences in grazing time between weaning groups. Calves left to nurse and graze with their dam consume less forage than calves left to graze alone (Stewart, 1971; Ansotegui et al., 1991). Therefore, during the 84-d period between weaning dates, forage would have been a smaller portion of the diet of LW calves that were still suckling than NW calves that were grazing alone. Numerous studies have described the potential for increasing the contents of PUFA in beef by grazing (French et al., 2000; Dannenberger et al., 2007; Duckett et al., 2009).

Cattle consuming fresh grass or grass silage compared with concentrates can result in greater concentrations of PUFA in both the phospholipid and triacylglyceride fractions of muscle (Noci et al., 2005; Nuernberg et al., 2005; Warren et al., 2008). The dietary concentration and proportion of PUFA will increase with increasing inclusion of fresh grass and increasing duration of grazing. Despite ruminal biohydrogenation, a proportion of dietary PUFA can bypass the rumen intact and be absorbed and deposited as body fat (Wood and Enser, 1997).

Smith et al. (2009a,b) and Hausman et al. (2009) found that stearoyl-CoA desaturase gene expression was virtually undetectable in the adipose tissue of just-weaned calves and in pasture-fed steers, but was highly expressed in the adipose tissue of corn-fed steers. Their data suggest that grazing may depress stearoyl-CoA desaturase gene expression, thus depressing $\Delta^9$-desaturase activity. In the present study, the desaturase index was not different between the NW and LW calves. Waters et al. (2009) demonstrated that supplementing n-3 fatty acids depressed stearoyl-CoA desaturase gene expression and suggested that grazing may have a similar effect due to increased absorption of α-linolenic acid (18:3n-3). It has also been suggested that increased concentrations of 18:2 *trans*-10,*cis-12* related to forage or pasture feeding could be the component depressing stearoyl-CoA desaturase gene expression in grazing animals (Hausman et al., 2009). In the present study, 18:3n-3 was affected by time of weaning, but this could not be separated from sire breed and muscle type effects, and no difference was observed in 18:2 *trans*-10,*cis*-12 concentrations due to any of the treatment effects. Cattle in this study were removed from pasture and finished on high-concentrate diets for 139 d. Therefore, any differences that may have been present in 18:3n-3 or 18:2 *trans*-10,*cis*-12 before entering the feedlot may have been diminished over the finishing period.

Time of weaning had an effect on percent total PUFA in Charolais-sired steers, whereas in Angus-sired steers percent PUFA was similar between weaning groups. Charolais-sired steers that were NW had a greater percent PUFA than LW Charolais-sired steers or Angus-sired steers from either weaning group. It is unclear why time of weaning had a larger effect on fatty acid profile in the Charolais-sired steers than the Angus-sired steers, and more research is needed to determine this interaction.

### *Conclusions*

Different fatty acids have different effects on human health and disease prevention. Improving the nutritional value and healthfulness of beef should emphasize beneficially altering the fatty acid composition and not simply fat content. Although all examined effects (sire breed, time of weaning, and muscle type) affected the fatty acid profile of marbling, muscle type appears to alter a wider array of specific fatty acids and classes than sire breed or time of weaning. This could be important in developing marketing strategies for different cuts of beef with different health benefits.

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