Level and source of fat in the diet of gestating beef cows: I. Effects on the prepartum performance of the dam and birth weight of the progeny[1]

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ABSTRACT: A 2-yr study was conducted to evaluate the effects of level and source of fat in the diet of gestating beef cows on their prepartum performance and birth weight of progeny. Each year, 75 multiparous (≥3 calving) pregnant Angus cows were stratified by BW (663 ± 21.5 kg) and BCS (2.6 ± 0.12; 1 to 5 scale) and randomly assigned to 1 of 15 outdoor pens. Subsequently, each pen was randomly assigned to 1 of 3 ($n = 5$) treatments: a low-fat diet (**LF**; 1.4 ± 0.12% EE) consisting of grass-legume hay, barley straw, and barley grain, or 1 of 2 high-fat diets (**HF**; 3.3 ± 0.20% EE) that included either a canola seed (**CAN**) or a flaxseed (**FLX**) based pelleted feed. Diets were formulated to meet the requirements of pregnant beef cows during the last 2 trimesters of gestation (0.183 ± 4.8 d), adjusted for changes in environmental conditions, and offered such that each pen on average received similar daily amounts of DE (31.2 ± 2.8 Mcal/cow), CP (1.36 ± 0.13 kg/cow), and DM (12.9 ± 1.0 kg/cow). Data were analyzed as a randomized complete block design with contrasts to separate the effects of level (LF vs. HF) and source (CAN vs. FLX) of fat. After 160 d on trial, conceptus corrected-BW (CC-BW) of LF cows (708 kg) and the proportion of overconditioned cows (13.2%) were greater ($P \leq 0.04$) than those of HF, with no difference ($P \geq 0.84$) between CAN and FLX for CC-BW (697 kg) and proportion of overconditioned cows (3.6% vs. 2.9%). Feeding FLX diet during gestation resulted in cows with a greater ($P \leq 0.01$) concentration of conjugated linolenic acid (0.12% vs. 0.05%) and n-3 (0.58% vs. 0.37%) fatty acids, and a tendency ($P = 0.09$) for conjugated linoleic acid concentration (1.05% vs. 0.88%) to be greater in subcutaneous adipose tissue (**SCAT**) when compared with cows fed the CAN diet. By the end of gestation, serum NEFA concentration of LF cows (592 µEq/L) was lower ($P < 0.01$) than that of HF cows, and FLX cows had greater ($P < 0.01$) serum NEFA concentration than CAN cows (636 vs. 961 µEq/L). Cows receiving the LF diet during gestation gave birth to lighter ($P < 0.01$) calves compared with those receiving the HF diets (40.2 vs. 42.9 kg), with no difference ($P = 0.24$) between calves born to CAN (42.4 kg) and FLX (43.3 kg) cows. In conclusion, these results suggest a partitioning of the ME in pregnant beef cows that is dependent on the type of dietary energy, resulting in heavier calves at birth for cows fed high-fat diets. Also, the type of fatty acid in the diet of gestating beef cows affected the fatty acid profile in SCAT and serum NEFA concentration.

Key words: beef cows, energy partitioning, fat level, fat source, gestation

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INTRODUCTION

In the northern Great Plains of North America, pregnant beef cows can be exposed to extreme low temperatures during winter which often overlaps with the last 2 trimesters of gestation. This is a critical time since fetal secondary myogenesis, muscle fiber hypertrophy, and adipogenesis occur during the last 2 trimesters of gestation (Du et al., 2010). As a result, during midgestation and late gestation, beef cows experience an increase in their energy requirements for maintenance and pregnancy to maintain body temperature and to ensure proper fetal growth (NRC, 2000). Therefore, formulating diets that provide sufficient energy in a cost-efficient manner is a major management goal for cow–calf producers to increase performance of their cows and calves.

Fat inclusion at levels up to 6% of the total DM intake of ruminants increases the energy density of high-forage diets without detrimental effects on animal performance and avoids the negative effects associated with starch inclusion (Palmquist, 1994; Bowman and Sanson, 1996; Hess et al., 2008). Also, compared with low-fat diets with similar energy content, high-fat diets have been shown to have a positive effect on reproductive performance of beef cows (Bellows, 1999; Bellows et al., 2001; Graham et al., 2001); and to be cost-effective when fed to backgrounding beef steers (Zenobi et al., 2014).

Adequate nutrient supply during gestation is not only necessary to meet the nutrient requirements of the dam but may also benefit the performance of the offspring of many mammalian species, including cattle (Wu et al., 2004; Du et al., 2010). The effects of underfeeding or overfeeding beef cows during gestation on performance of the offspring have been extensively documented (Funston et al., 2010), but few studies have looked at the effects of nutrient source (i.e., starch vs. fat). Radunz et al. (2010) fed multiparous beef cows from midgestation until calving with similar amounts of NE_m using a grass hay–based diet (244 g/d of crude fat), or 2 diets supplemented with corn or corn DDGS (270 and 455 g/d of crude fat, respectively). It was found that calves born to the cows fed the corn and corn DDGS diets were heavier at birth than those born to cows fed grass hay. However, because cows fed corn DDGS consumed greater amounts of CP than those fed corn (1.1 vs. 1.6 kg/d of CP), it was not clear if the increase in birth weight for corn DDGS calves was a result of the source of energy or level of CP intake of the dam over gestation.

Compared with low-fat diets, feeding high-fat diets over gestation has shown to improve placental nutrient transport to the fetus in mice, hence increasing the fetal weight of the progeny (Jones et al., 2009). Moreover, placental and fetal tissues from humans and rodents have been reported to have a preference for absorption of long-chained PUFA, especially during the late stages of gestation (Herrera, 2002; Jones et al., 2007). This has important implications as low maternal intake of n-6 and n-3 fatty acids during gestation has resulted in reduced neonatal growth in humans (Jumpsen et al., 1997). However, such effects of level and source of fat in the diet of the dam during gestation on performance of the progeny have not been studied in cattle.

In western Canada and the northwestern United States, there are a number of by-product feeds that vary in oil and fatty acid content. Examples include oilseeds such as off-grade canola seed and flaxseed, which are high in monounsaturated fatty acids (**MUFA**) and PUFA, respectively. Research has shown that relative to conventional feed sources, inclusion of these by-products in the form of blended pelleted feeds has resulted in equal or superior performance of growing cattle (Zenobi et al., 2014; Añez-Osuna et al., 2015). Such high-fat by-product feeds may also be viable supplements for gestating beef cows to meet pregnancy requirements and could potentially improve the prenatal and postnatal growth of progeny through developmental programming mechanisms.

This article is the first of 2 companion papers that address the effects of level and source of fat in the diet of gestating beef cows. The objective was to evaluate the effects of feeding beef cows over the last 2 trimesters of gestation with a low-fat diet or 2 high-fat diets, which differed in their fatty acid composition (MUFA vs. PUFA), on the prepartum performance of the dam and birth weight of the progeny. The companion paper (Añez-Osuna et al., unpublished data) addresses the calving to weaning responses of the cow, and calving to slaughter responses of the progeny.

MATERIALS AND METHODS

Location, Animals, and Treatments

Location A 2-yr study (2014 to 2015 and 2015 to 2016 for years 1 and 2, respectively) was conducted from late October to late April (on average) at the Termuende Research Ranch of the Western Beef Development Centre (**WBDC**) near Lanigan (51°51′N, 105°02′W), Saskatchewan, Canada.

Over the 2 yr of the study, the monthly average of the mean daily temperatures reported for the Lanigan area (51°40′N, 105°24′W) were 6.4 ± 0.5, −6.2 ± 5.0, −10.0 ± 0.4, −12.4 ± 0.6, −12.7 ± 6.8, −2.0 ± 0.2, and 4.5 ± 0.7 °C from October to April, respectively (Government of Canada, Environment and Natural Resources, http://weather.gc.ca). These values were similar for October to February (4.0 ± 2.3, −5.6 ± 4.7, −14.2 ± 4.4, −13.2 ± 2.5, and −13.2 ± 5.5 °C, respectively) and slightly warmer for March and April (−5.6 ± 5.7 and 1.9 ± 3.6 °C, respectively) to the 5-yr (2012 to 2016) average reported at the same location.

Animals and housing All animals were cared for in accordance with the Canadian Council on Animal Care (2009) guidelines, and all experimental procedures were approved by the University of Saskatchewan Animal Care Committee (Protocol No. 20090107).

Animals were obtained from the main herd of the WBDC's research ranch. Each year, 75 multiparous (≥3 calving) pregnant Angus cows were housed in 15 outdoor research pens (7.4 × 24.5 m) separated by metal rail fences and equipped with feed bunks, water bowls, and 20% porosity windbreaks. Wood chips were used for bedding and provided twice per week. The same animals were used for each year of the study unless culled for injury or failure to conceive, in which case, similar replacements were obtained from the same herd. Prior to the start of the trial, all cows were managed together and exposed to a 63-d breeding season during the summer starting on 2 July and 5 July for years 1 and 2, respectively. Four half-sibling, registered Angus bulls were used as sires (25:1 cow to bull) for both years. Bulls were semen tested prior to breeding each year. Forty-five days after ending the breeding season, all cows were pregnancy checked by a veterinarian using an Easi-Scan Curve ultrasound machine (3.0 to 7.0 MHz; BCF Technology Ltd., Rochester, MN). At this time, a vitamin ADE (Bimeda-MTC, Cambridge, ON) injection (5 mL) was administered to each cow.

Treatments, feeding, and handling Each year (24 and 23 October for years 1 and 2, respectively), cows were stratified by initial BW (662 ± 52.4 kg) and BCS, and divided into 15 homogenous groups (5 cows per group). Subsequently, each group was randomly assigned to 1 of the 15 outdoor research pens, and each pen was then randomly assigned to 1 of 3 replicated (n = 5) dietary treatments which consisted of: a low-fat (**LF**) diet (1.4 ± 0.13% EE) or 1 of 2 high-fat (**HF**) diets (3.3 ± 0.10% EE). Hay consisting of bromegrass (*Bromus* sp.) and alfalfa (*Medicago sativa* L.), barley straw, rolled barley grain, and 2 high-fat pelleted feeds were used as ingredients to formulate the diets (Table 1). The 2 high-fat pellets were formulated using canola seed (**CAN**) as a source of MUFA or using flaxseed (**FLX**) as a source of PUFA. High-fat diets (CAN and FLX) were formulated to provide each cow with 300 g of fat from pelleted feeds daily. Feeding amounts were such that each pen received equal amounts of DE, CP, and total DM. Diets were formulated to meet the DE and CP intake requirements of pregnant beef cows over the second and third trimesters of gestation according to NRC (2000). The goal was to have the cows maintain BW over the course of the trial while accounting for the estimated increase due to uterine and fetal tissue growth corresponding to a projected 40-kg calf at birth (NRC, 2000). The amounts fed were adjusted every 2 wk according to estimated day of gestation, gained weight, and actual changes in weather conditions. Diets were offered daily as total mixed rations (**TMR**) using a mixer wagon with feeding starting at 0800 h, and bunks were cleaned every 2 wk due to accumulation of orts if needed. Each year, the trial lasted from the start of the second trimester of gestation until calving (183 ± 14 d). Prior to estimated calving date (23 ± 14 d before calving), cows were moved from their replicate pen and relocated according to treatment into one of 3 common calving pens (76 × 73 m) equipped with feed bunks and water bowls. Cows continued receiving their treatment diets in their respective group pen until calving. All animals had ad libitum access to a 2:1 mineral [as-fed basis: 15.5% Ca, 7% P, 30 ppm Se, 20 ppm Co, 200 ppm I, 1,500 ppm Cu, 5,000 ppm Mn, 5,000 ppm Zn, 1,000 ppm Fe, 1.0 ppm F (max), 500,000 IU/kg vitamin A (min), 50,000 IU/kg vitamin D (min), 2,500 IU/kg vitamin E (min); Cargill Animal Nutrition, Manitoba, Canada] and cobalt-iodized salt (99.0% NaCl, 39.0% Na, 150 ppm I, 100 ppm Co; FeedRite Ltd., Humboldt, Saskatchewan, Canada) at all times.

Data Collection

Feeds and DMI Grass-legume hay, barley straw, and barley grain were collected weekly and placed in a forced air oven at 55 °C for 48 h for DM determination. Pelleted feed samples were also collected weekly. All feed samples were ground to pass a 1-mm screen using a Thomas-Wiley Laboratory Mill (Model 4, Thomas Scientific, Swedesboro, NJ)

Table 1. Nutrient and fatty acid composition (average ± SD) of feed ingredients by year

Feeds[1]	Grass hay		Barley straw		Barley grain		CAN pellet		FLX pellet	
Year	1	2	1	2	1	2	1	2	1	2
Ingredient[2], % as fed										
Oat hulls	—	—	—	—	—	—	40.0	40.0	40.0	40.0
Wheat	—	—	—	—	—	—	41.0	41.0	41.0	41.0
DDGS	—	—	—	—	—	—	2.0	2.0	2.0	2.0
Feed binder	—	—	—	—	—	—	2.0	2.0	2.0	2.0
Canola seed	—	—	—	—	—	—	15.0	15.0	—	—
Flaxseed	—	—	—	—	—	—	—	—	15.0	15.0
Nutrients[3], % DM										
DM, % as fed	75.9 ± 5.61	76.0 ± 7.62	71.7 ± 8.34	69.3 ± 6.82	87.4 ± 3.01	84.0 ± 2.21	90.1 ± 1.87	88.9 ± 1.60	88.9 ± 2.68	88.8 ± 1.76
CP	10.7 ± 0.15	12.5 ± 0.19	6.65 ± 0.17	8.09 ± 0.17	12.2 ± 0.05	13.0 ± 0.21	12.4 ± 0.25	13.4 ± 0.30	13.0 ± 0.92	13.1 ± 0.22
ADF	46.2 ± 0.75	48.8 ± 0.52	51.7 ± 0.14	52.5 ± 0.33	14.3 ± 0.19	8.84 ± 0.45	20.8 ± 0.38	26.2 ± 0.29	18.8 ± 1.15	24.3 ± 0.39
NDF	65.5 ± 0.92	66.1 ± 1.00	75.0 ± 0.11	75.2 ± 0.22	31.0 ± 0.63	21.7 ± 1.10	35.7 ± 0.41	44.4 ± 0.75	29.9 ± 1.09	42.5 ± 1.97
EE	1.38 ± 0.02	1.55 ± 0.04	1.16 ± 0.01	0.87 ± 0.07	1.95 ± 0.15	1.73 ± 0.33	7.51 ± 0.10	9.28 ± 0.17	6.36 ± 0.18	8.05 ± 0.25
Calcium	0.68 ± 0.03	0.96 ± 0.05	0.38 ± 0.02	0.35 ± 0.02	0.09 ± 0.00	0.07 ± 0.00	0.83 ± 0.04	0.23 ± 0.00	0.13 ± 0.00	0.49 ± 0.01
Phosphorus	0.22 ± 0.01	0.21 ± 0.01	0.16 ± 0.01	0.16 ± 0.01	0.43 ± 0.00	0.37 ± 0.02	0.30 ± 0.00	0.38 ± 0.00	0.31 ± 0.01	0.37 ± 0.01
TDN	49.9 ± 0.85	46.9 ± 0.59	43.7 ± 0.16	42.7 ± 0.38	74.5 ± 0.09	77.2 ± 0.22	71.4 ± 0.18	68.8 ± 0.14	72.4 ± 0.55	69.7 ± 0.19
Fatty acid[4], % of total										
16:0	33.4 ± 0.95	30.5 ± 0.84	31.0 ± 0.28	28.1 ± 1.81	28.3 ± 0.51	27.6 ± 0.71	10.1 ± 0.62	8.13 ± 0.01	10.4 ± 0.06	9.57 ± 0.15
18:0	4.00 ± 0.48	4.93 ± 0.26	3.72 ± 0.09	4.27 ± 0.25	1.63 ± 0.05	1.67 ± 0.05	2.17 ± 0.08	1.84 ± 0.01	3.01 ± 0.04	3.34 ± 0.10
*c*9-18:1	8.98 ± 2.32	9.06 ± 0.77	11.1 ± 0.53	13.0 ± 1.84	18.1 ± 1.29	17.0 ± 0.21	53.5 ± 0.75	53.2 ± 0.14	19.9 ± 0.09	19.4 ± 0.29
*c*11-18:1	1.27 ± 0.15	1.58 ± 0.11	1.48 ± 0.07	1.90 ± 0.18	1.18 ± 0.09	1.08 ± 0.03	3.86 ± 0.06	4.14 ± 0.03	0.88 ± 0.01	0.88 ± 0.00
18:2n-6	13.6 ± 0.50	15.3 ± 0.59	16.6 ± 0.40	17.3 ± 2.52	39.8 ± 1.01	41.3 ± 0.79	20.2 ± 0.94	21.1 ± 0.04	23.6 ± 0.14	20.7 ± 0.23
18:3n-3	22.7 ± 2.63	22.4 ± 1.77	11.6 ± 0.61	11.5 ± 2.22	6.95 ± 0.34	7.39 ± 0.32	6.57 ± 0.58	8.24 ± 0.16	40.4 ± 0.25	44.6 ± 0.34
ΣSFA	49.5 ± 0.45	48.7 ± 0.95	55.8 ± 0.73	52.3 ± 3.60	31.9 ± 0.57	31.3 ± 0.85	13.9 ± 0.79	11.4 ± 0.03	14.4 ± 0.13	13.8 ± 0.25
ΣMUFA	14.0 ± 2.23	13.4 ± 0.90	15.7 ± 0.21	18.7 ± 1.62	21.3 ± 1.46	19.9 ± 0.26	59.3 ± 0.83	59.2 ± 0.18	21.6 ± 0.09	21.0 ± 0.29
ΣPUFA	36.5 ± 2.15	37.8 ± 1.32	28.5 ± 0.92	29.0 ± 4.48	46.8 ± 1.34	48.8 ± 1.07	26.8 ± 1.50	29.4 ± 0.18	64.0 ± 0.21	65.3 ± 0.54

[1]CAN pellet = pelleted feed formulated using canola seed; FLX pellet = pelleted feed formulated using flaxseed.

[2]DDGS = dry distillers grains with solubles; feed binder = sodium bentonite (Canapell; Canadian Clay Products, Inc. Wilcox, SK, Canada).

[3]EE = ether extract; TDN = total digestible nutrients. TDN was calculated using the Pennsylvania-State equations (Adams, 1980).

[4]ΣSFA = sum of saturated fatty acids; ΣMUFA = sum of monounsaturated fatty acids; ΣPUFA = sum of polyunsaturated fatty acids.

and stored at −20 °C. Ground feed samples were composited (DM basis) after every 5 or 6 wk of collection to obtain 2 composite samples per trimester corresponding to the first and second half of the second and third trimesters of gestation. Composite samples were stored at −20 °C until analysis.

The total amount of TMR fed to each treatment was recorded daily and distributed equally across pens. Thus, within treatment, all pens received the same daily amount of TMR. Total amounts of orts were collected every 2 wk, recorded, and a representative sample was placed in a forced air oven at 55 °C for 48 h to determine DM. Dry matter intake was calculated using the difference between the quantity of DM offered and the quantity of DM refused.

Body weight To minimize variation due to rumen fill, each cow was weighed over 2 consecutive days at the start of the trial and at the time of relocation in the common calving pens. Throughout the 160 d of the winter feeding, all cows were weighed once every 2 wk with weights measured before feeding. Throughout the calving season, all cows were checked twice daily for signs of parturition, and birth weight of each calf was determined within the first 24 h after birth. Calving date and birth weight of each calf were used to estimate fetal and associated uterine tissue growth (assuming a gestation of 283 d) using the NRC (2000) model. The conceptus corrected-BW (**CC-BW**) of each cow was calculated by subtracting the fetal and gravid uterine weights from the pregnant-BW.

Body condition score and subcutaneous fat thickness At the start of the trial and at relocation into common calving pens, the BCS of each cow was determined by the same experienced technician using the Scottish scale where 1 = emaciated and 5 = grossly fat (Lowman et al., 1976; Wildman et al., 1982). Ultrasound measurements of subcutaneous fat thickness (**SCFT**) over the third quarter of the longissimus dorsi muscle, between the 12th and 13th rib, and at the thurl location on the rump area were determined on each cow at the start and at the end of the feeding period, and at calving using an Aloka SSD-500V ultrasound machine and an Aloka UST-5044 probe (3.5 MHz-17 cm; Aloka Inc., Wallingford, CT).

Blood serum and subcutaneous adipose tissue Each year at the start of the trial, a representative sample of 15 cows were randomly selected (n = 1 cow/pen) and used for blood and adipose tissue collection. At the time of relocation in common calving pens, 30 cows were randomly selected (n = 2 cows/pen) and used for blood and adipose tissue collection. Blood samples were collected from each cow via coccygeal venipuncture into 10-mL untreated vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ). Blood samples were allowed to clot at room temperature for 30 min and centrifuged (2,000 × g at 4°C for 15 min), and serum was harvested into 1.5-mL tubes (Eppendorf, GCS, New York, NY) and refrigerated at −20 °C until analysis. Subcutaneous adipose tissue (**SCAT**) biopsies (approximately 5 g) were taken from the caudal portion of the tail-head of each cow under local anesthesia using 4 mL of lidocaine HCl 2% (Zoetis Canada Inc., Kirkland, QC). Adipose tissue biopsies were removed, placed into 60-mL sterile polyethylene bags (Fisher Scientific, Ottawa, ON), and stored at −20 °C until analysis.

Laboratory Analysis

Feeds All feed samples were analyzed in duplicate for nutrient composition by Cumberland Valley Analytical Services Inc. (Hagerstown, MD). Grass-legume hay and barley straw samples were analyzed by near infrared spectroscopy using a Foss NIRSystems 5000 (NIR Systems, Inc., Silver Spring, MD) for determination of DM [SE of calibration (**SEC**) = 0.31, regression coefficient (R^2) = 0.93], CP (SEC = 0.51, R^2 = 0.99), ADF (SEC = 1.24, R^2 = 0.95), NDF (SEC = 1.69, R^2 = 0.96), EE (SEC = 0.32, R^2 = 0.87), ash (SEC = 0.84, R^2 = 0.85), Ca (SEC = 0.07, R^2 = 0.80), and P (SEC = 0.04, R^2 = 0.80). Barley grain and pelleted feed samples were analyzed for DM by drying at 135 °C for 2 h (method 930.15; AOAC, 2012), CP (method 990.03; AOAC, 2012) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St. Joseph, MI), EE using a tecator extraction unit (method 2003.05; AOAC, 2012), ADF (method 973.18; AOAC, 2012), ash (method 942.05; AOAC, 2012), and Ca and P (method 985.01; AOAC, 2012). The method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite was used to determine NDF content. The Pennsylvania-State equations based on ADF were used to calculate the total digestible nutrient (**TDN**) values for all feeds (Adams, 1980). Digestible energy, ME, NE_m, and NE_g were calculated according to NRC (2000). Metabolizable protein was estimated using the 2016 Nutrient Requirements of Beef Cattle model and associated feed library values for degradable and undegradable protein (NASEM, 2016).

Blood metabolites Blood serum samples were used for determination of NEFA and β-hydroxybutyrate (**BHBA**) concentrations. Serum NEFA concentration was determined using the NEFA-HR (2) kit (Wako Diagnostics Corp., Richmond, VA). Serum BHBA concentration was determined through the enzymatic oxidation of BHBA to acetoacetate caused by incubation in 3-hydroxybutrate dehydrogenase (Williamson et al., 1962). The associated reduction of NAD to NADH was determined through photometric methods at a wavelength of 340 nm using a microplate spectrophotometer (Epoch 2, Biotek Instruments Inc., Winooski, VT). The interplate and intraplate assay CV was 5.4 ± 4.3% and 3.2 ± 0.7%, respectively.

Fatty acid extraction and gas chromatography Fatty acid methyl esters (**FAME**) were obtained from feeds and SCAT samples. Fatty acids of feed samples were methylated using the method of Palmquist and Jenkins (2003) and heptadecenoic acid (standard no. U-42M from Nu-Chek Prep Inc., Elysian, MN) as internal standard. Briefly, 150 mg of forage and barley grain samples, and 50 mg of pelleted feed samples were methylated at 90 °C for 2 h using 3 N methanolic HCl. Internal standard (4 mg) in toluene was added prior to addition of the methylating reagent. After methylation, samples were cooled, 10 mL of 6% K_2CO_3 added and FAME were extracted into hexane. Completeness of methylation was determined and FAME purified by TLC using silica gel G plates and hexane:diethyl ether:acetic acid (85:15:1) as a developing solvent. For adipose tissue samples, 40 ± 5 mg of thin shavings was weighed into a culture tube with teflon lined cap and freeze-dried overnight to constant weight. Subsequently, samples were methylated using 0.5 N sodium methoxide. Internal standard (4 mg) was added prior to addition of the methylating reagent. Fatty acid methyl esters obtained from feeds and adipose tissue samples were analyzed using a Varian CP-3800 gas chromatograph (Varian Inc., Walnut Creek, CA) using the conditions described by Dugan et al. (2007). Fatty acids were identified using reference standard no. 603 from Nu-Chek Prep Inc. (Elysian, MN). Branched-chain FAME were identified using a GLC reference standard BC-Mix1 from Applied Science (State College, PA). The UC-59M standard from Nu-Chek Prep, which contains all 4 positional conjugated linoleic acid (**CLA**) isomers, was used for CLA isomers. Biohydrogenation intermediates, such as *trans*-18:1 CLA isomers, not included in the standard mixtures were identified by their retention times and elution orders as reported in literature (Cruz-Hernandez et al., 2004; Kramer et al., 2008; Gomez-Cortes et al., 2009), and this included recently identified Δ-9 desaturation products of *trans*-18:1 isomers (Vahmani et al., 2016a). The FAME were quantified using chromatographic peak area and internal standard-based calculations as detailed in Vahmani et al. (2017).

Statistical Analysis

Of the 75 cows used each year of the study, 3 cows (1 from each treatment) died during the winter-feeding period from natural cause unrelated to treatment. Data from these animals were removed from the analysis. As well, data from cows with multiple gestation (2 FLX, 1 CAN, and 1 CON) were removed before analysis. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC). The average of each research pen where cows received their treatment diets during gestation represented the experimental unit. Data were analyzed as a randomized complete block design using the Mixed procedure. The statistical model included the fixed effect of treatment and the random effect of year. The average number of days cows was exposed to treatment diets (from the start of trial until calving), as well as the proportion of cows carrying heifer calves within research pen was also included in the model as covariates. The Glimmix procedure was used to analyze categorical data such as BCS using the same model. For analysis of BCS data, cattle were grouped based on the classification reported by Herd and Sprott (1986) into 3 categories: thin cows with BCS of 2.0 or less, optimal cows with BCS of 2.5 or 3.0, and overconditioned cows with BCS of 3.5 or greater. The Kenward–Roger option was used to estimate denominator df. Preplanned contrasts were used to determine the effects of level (LF vs. HF) and source (CAN vs. FLX) of fat. Significant differences were declared at $P < 0.05$ and trends at $P < 0.10$.

RESULTS AND DISCUSSION

Feed and Diet Compositions

The nutrient composition of the hay, straw, barley grain, and high-fat pelleted feeds are shown in Table 1. The high-fat pellets were formulated using by-product feeds derived from local processing of cereal grains in western Canada and proven to meet the nutrient requirements of beef cattle (Zenobi et al., 2014; Añez-Osuna et al.,

2015). Formulation of high-fat pelleted feeds was such that the only difference among their ingredients was the major source of fat (canola seed vs. flaxseed). As a result, the level of fat and the fatty acid profiles reflected the source of fat. For both years, CAN pellets had greater total MUFA content (59.3% and 59.2%) than FLX pellets (21.6% and 21.0%). The major fatty acid responsible for the difference in MUFA content was oleic acid (*c*9-18:1) averaging 53.4 ± 0.53% and 19.6 ± 0.35% for CAN and FLX, respectively, over both years. In contrast, total PUFA content for FLX pellets (64.0% and 65.3%) was greater than that of CAN pellet (26.8% and 29.4%) in both years. The main fatty acid responsible for the difference in PUFA was α-linolenic acid (18:3n-3) with a 2-yr average of 7.41 ± 0.97% and 42.5 ± 2.27% for CAN and FLX, respectively. Within each year of this study, there was little variation in the fatty acid content of the 2 pelleted feeds. In year 1, the 18:3n-3 content of CAN pellet had the largest CV (8.8%), whereas the *c*9-18:1 content of FLX pellet had the smallest CV (0.5%). For year 2, stearic acid (18:0) content in FLX pellet had the largest CV (3.0%), whereas the palmitic (16:0) and linoleic (18:2n-6) content of CAN pellet had the smallest CV value (0.2%). This consistent fatty acid profile in the high-fat pellets in each year indicates a relatively high natural antioxidant activity in both canola seed and flaxseed (Siger et al., 2008).

The ingredient and nutrient composition of dietary treatments are shown in Table 2. On average, over the second and third trimesters of gestation as well as over the entire feeding period, dietary treatments were similar in energy (2.38 ± 0.10, 2.43 ± 0.13, and 2.44 ± 0.09 Mcal/kg of DE for LF, CAN, and FLX respectively) and CP (10.3 ± 0.5%, 10.6 ± 0.4%, and 10.7 ± 0.4% for LF, CAN, and FLX, respectively) content. As expected, the average dietary fat (**EE**) content by trimester of gestation and over

Table 2. Ingredient, nutrient, and fatty acid composition (average ± SD) of treatment diets by trimester of gestation

Treatment[1]	LF			CAN			FLX		
Trimester	Second	Third	Average ± SD	Second	Third	Average ± SD	Second	Third	Average ± SD
Ingredient, % DM									
Grass hay	33.7 ± 2.56	36.4 ± 2.44	35.0 ± 2.84	27.2 ± 1.82	29.0 ± 2.27	28.1 ± 2.22	28.2 ± 2.82	29.9 ± 2.30	29.0 ± 2.73
Barley straw	38.3 ± 6.87	36.1 ± 2.33	37.3 ± 5.34	35.9 ± 8.38	33.7 ± 5.30	34.9 ± 7.17	33.4 ± 6.48	33.1 ± 1.74	33.3 ± 4.86
Barley grain	28.0 ± 7.48	27.5 ± 3.50	27.8 ± 5.94	7.45 ± 5.10	9.11 ± 1.77	8.23 ± 3.98	1.93 ± 2.29	4.38 ± 3.55	3.08 ± 3.19
CAN pellet	—	—	—	29.4 ± 4.18	28.2 ± 2.98	28.8 ± 3.71	—	—	—
FLX pellet	—	—	—	—	—	—	36.4 ± 7.43	32.6 ± 3.29	34.6 ± 6.15
Nutrient[2], % DM									
CP	10.3 ± 0.44	10.3 ± 0.56	10.3 ± 0.50	10.5 ± 0.32	10.7 ± 0.40	10.6 ± 0.37	10.6 ± 0.42	10.9 ± 0.37	10.7 ± 0.42
ADF	39.4 ± 3.01	39.4 ± 1.07	39.4 ± 2.31	39.5 ± 4.15	38.9 ± 2.40	39.2 ± 3.44	38.9 ± 3.22	38.7 ± 1.14	38.8 ± 2.46
NDF	58.5 ± 2.60	58.5 ± 0.57	58.5 ± 1.93	58.6 ± 4.73	58.1 ± 2.62	58.4 ± 3.88	56.9 ± 5.12	57.1 ± 1.42	57.0 ± 3.85
EE	1.35 ± 0.14	1.45 ± 0.07	1.40 ± 0.12	3.30 ± 0.20	3.32 ± 0.08	3.31 ± 0.16	3.29 ± 0.29	3.24 ± 0.15	3.27 ± 0.23
Calcium	0.44 ± 0.07	0.45 ± 0.05	0.45 ± 0.06	0.53 ± 0.05	0.51 ± 0.06	0.52 ± 0.06	0.46 ± 0.10	0.46 ± 0.07	0.46 ± 0.09
Phosphorus	0.25 ± 0.03	0.24 ± 0.02	0.25 ± 0.02	0.25 ± 0.01	0.25 ± 0.00	0.25 ± 0.01	0.24 ± 0.01	0.24 ± 0.01	0.24 ± 0.01
TDN	54.0 ± 2.87	54.0 ± 1.27	54.0 ± 2.26	54.9 ± 3.50	55.3 ± 2.04	55.1 ± 2.90	55.4 ± 2.80	55.4 ± 0.90	55.4 ± 2.13
NEm, Mcal/kg	1.09 ± 0.10	1.09 ± 0.04	1.09 ± 0.08	1.12 ± 0.12	1.14 ± 0.07	1.13 ± 0.10	1.14 ± 0.10	1.14 ± 0.03	1.14 ± 0.07
NEg, Mcal/kg	0.52 ± 0.09	0.53 ± 0.04	0.53 ± 0.07	0.56 ± 0.11	0.57 ± 0.06	0.56 ± 0.09	0.57 ± 0.09	0.57 ± 0.03	0.57 ± 0.07
Fatty acid[3], % of total									
16:0	28.2 ± 0.74	28.2 ± 0.66	28.2 ± 0.70	11.8 ± 1.36	12.7 ± 1.20	12.3 ± 1.36	11.5 ± 0.52	12.3 ± 0.46	11.9 ± 0.63
18:0	2.01 ± 0.19	2.06 ± 0.10	2.03 ± 0.16	2.07 ± 0.05	2.12 ± 0.13	2.09 ± 0.10	3.14 ± 0.15	3.18 ± 0.11	3.16 ± 0.13
*c*9-18:1	17.3 ± 0.90	16.1 ± 0.33	16.7 ± 0.91	47.6 ± 1.38	46.8 ± 0.83	47.2 ± 1.21	19.0 ± 0.42	19.1 ± 0.31	19.1 ± 0.37
*c*11-18:1	1.24 ± 0.05	1.20 ± 0.05	1.22 ± 0.05	3.59 ± 0.26	3.55 ± 0.13	3.57 ± 0.19	0.93 ± 0.03	0.94 ± 0.03	0.93 ± 0.03
18:2n-6	36.6 ± 0.51	37.2 ± 0.73	36.9 ± 0.70	22.4 ± 1.00	22.5 ± 0.65	22.5 ± 0.85	22.4 ± 1.20	22.9 ± 0.53	22.7 ± 0.98
18:3n-3	7.94 ± 0.54	8.35 ± 0.35	8.13 ± 0.50	7.93 ± 0.61	7.56 ± 0.99	7.76 ± 0.83	40.0 ± 1.33	38.3 ± 0.67	39.2 ± 1.34
ΣSFA	34.7 ± 0.92	34.9 ± 0.70	34.8 ± 0.81	16.3 ± 1.36	17.5 ± 1.31	17.0 ± 1.34	16.4 ± 0.71	17.6 ± 0.52	17.1 ± 0.84
ΣMUFA	20.7 ± 1.14	19.4 ± 0.33	20.1 ± 0.99	53.4 ± 1.55	52.3 ± 0.79	52.7 ± 1.32	20.9 ± 0.43	21.0 ± 0.27	21.0 ± 0.33
ΣPUFA	44.6 ± 0.97	45.7 ± 0.78	45.1 ± 1.02	30.4 ± 0.67	30.2 ± 1.59	30.3 ± 1.20	62.4 ± 0.60	61.3 ± 0.32	61.9 ± 0.74

[1]LF = low-fat diet; CAN = high-fat diet including canola seed-based pelleted feed; FLX = high-fat diet including flaxseed- based pelleted feed.

[2]EE = ether extract; TDN = total digestible nutrients. TDN was calculated using the Pennsylvania-State equations (Adams, 1980). NEm and NEg were calculated using the NRC (2000) summative equations.

[3]ΣSFA = sum of saturated fatty acids; ΣMUFA = sum of monounsaturated fatty acids; ΣPUFA = sum of polyunsaturated fatty acids.

the entire feeding period was different between LF and HF diets. The average fat (EE) content was 1.40 ± 0.12% for LF diet, and 3.31 ± 0.16% and 3.27 ± 0.23% for CAN and FLX treatments, respectively. Also, the fatty acid profile of treatment diets differed across treatment diets. Over the 2 years, the average total saturated fatty acid content of the LF diet (34.8%) was twice that of the CAN (17.0%) and FLX (17.1%) diets. The average MUFA content of CAN diet was 2.5 times greater than that of the FLX diet (52.7% vs. 21.0%), whereas the average PUFA content of FLX diet was twice that of the CAN diet (61.9% vs. 30.3%).

Dry Matter and Nutrient Intake

The DM and nutrient intake of dietary treatments are shown in Table 3. As per the experimental design, the average DMI over the entire feeding period was similar across treatments (12.9 ± 0.9, 12.9 ± 0.9, and 12.8 ± 1.0 kg/cow/d for LF, CAN, and FLX, respectively). Also, when expressed relative to BW, the DMI was similar across treatment with averages of 1.81 ± 0.14, 1.82 ± 0.14, and 1.80 ± 0.17 as percentage of BW over the entire feeding period for LF, CAN, and FLX treatments, respectively. In the same way, the average energy and protein intakes over the entire feeding period were similar across treatments. On average, estimated consumption of ME and MP were 25.2 ± 2.2, 25.7 ± 2.3, and 25.7 ± 2.4 Mcal/d and 0.70 ± 0.04, 0.74 ± 0.04, and 0.75 ± 0.05 kg/d for LF, CAN, and FLX treatments, respectively. According to NASEM (2016), a mature (655 kg of BW) and pregnant (42 kg of calf birth weight) beef cow under similar environmental conditions requires on average 20.5 Mcal/d of ME and 0.57 kg/d of MP during the second and third trimesters of gestation. In the present study, it was observed that the average ME and MP consumption of all treatment groups exceeded requirements by 24.7% and 26.2%, respectively.

Table 3. Dry matter and nutrient intake of pregnant beef cows fed their treatment diets during the second and third trimesters of gestation

Treatment[1]	LF			CAN			FLX		
Trimester	Second	Third	Average ± SD	Second	Third	Average ± SD	Second	Third	Average ± SD
Ration DMI									
kg/cow/d	12.4 ± 1.18	13.5 ± 0.47	12.9 ± 1.05	12.5 ± 1.12	13.4 ± 0.36	12.9 ± 0.98	12.4 ± 1.31	13.4 ± 0.40	12.8 ± 1.11
% of BW	1.79 ± 0.17	1.82 ± 0.08	1.81 ± 0.14	1.81 ± 0.18	1.84 ± 0.06	1.82 ± 0.14	1.79 ± 0.22	1.82 ± 0.06	1.80 ± 0.17
Nutrient[2], kg/d									
CP	1.28 ± 0.13	1.39 ± 0.12	1.33 ± 0.14	1.31 ± 0.13	1.44 ± 0.08	1.37 ± 0.12	1.31 ± 0.15	1.45 ± 0.08	1.38 ± 0.14
ADF	4.90 ± 0.59	5.31 ± 0.31	5.09 ± 0.52	4.92 ± 0.65	5.24 ± 0.42	5.07 ± 0.58	4.81 ± 0.61	5.17 ± 0.28	4.98 ± 0.51
NDF	7.28 ± 0.74	7.88 ± 0.31	7.56 ± 0.65	7.31 ± 0.84	7.82 ± 0.51	7.55 ± 0.75	7.05 ± 0.94	7.64 ± 0.38	7.33 ± 0.79
EE	0.17 ± 0.03	0.20 ± 0.01	0.18 ± 0.02	0.41 ± 0.04	0.45 ± 0.02	0.43 ± 0.03	0.41 ± 0.05	0.43 ± 0.03	0.42 ± 0.04
Calcium	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
Phosphorus	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
TDN	6.71 ± 0.72	7.27 ± 0.15	6.97 ± 0.60	6.84 ± 0.76	7.43 ± 0.22	7.12 ± 0.64	6.86 ± 0.81	7.40 ± 0.16	7.12 ± 0.66
NEm, Mcal/d	13.5 ± 1.73	14.6 ± 0.34	14.1 ± 1.40	14.0 ± 1.94	15.2 ± 0.76	14.6 ± 1.63	14.1 ± 1.90	15.2 ± 0.35	14.6 ± 1.51
ME, Mcal/d	24.2 ± 2.59	26.3 ± 0.54	25.2 ± 2.17	24.7 ± 2.75	26.8 ± 0.79	25.7 ± 2.32	24.8 ± 2.94	26.8 ± 0.59	25.7 ± 2.38
MP, kg/d	0.68 ± 0.05	0.72 ± 0.02	0.70 ± 0.04	0.71 ± 0.06	0.76 ± 0.01	0.74 ± 0.05	0.72 ± 0.07	0.77 ± 0.02	0.75 ± 0.06
Fatty acid[3], g/d									
Total	156 ± 23.5	164 ± 16.5	160 ± 20.9	361 ± 57.6	389 ± 28.4	374 ± 48.2	367 ± 68.4	369 ± 12.9	368 ± 50.5
16:0	43.9 ± 6.89	46.4 ± 5.12	45.1 ± 6.24	43.3 ± 11.2	49.7 ± 7.76	46.3 ± 10.3	42.4 ± 8.17	45.6 ± 2.49	43.9 ± 6.38
18:0	3.09 ± 0.30	3.36 ± 0.19	3.21 ± 0.29	7.47 ± 1.26	8.26 ± 1.05	7.84 ± 1.23	11.4 ± 1.75	11.8 ± 0.64	11.6 ± 1.35
*c*9-18:1	27.0 ± 5.11	26.4 ± 2.91	26.7 ± 4.22	171 ± 24.0	182 ± 15.6	176 ± 21.2	70.1 ± 14.1	70.6 ± 2.67	70.3 ± 10.4
*c*11-18:1	1.93 ± 0.35	1.96 ± 0.14	1.94 ± 0.27	12.8 ± 1.50	13.8 ± 0.70	13.3 ± 1.28	3.39 ± 0.57	3.49 ± 0.17	3.43 ± 0.43
18:2n-6	56.9 ± 8.69	61.2 ± 6.82	58.9 ± 8.13	81.2 ± 15.7	87.4 ± 4.57	84.1 ± 12.2	83.0 ± 18.8	84.7 ± 3.37	84.0 ± 13.9
18:3n-3	12.3 ± 1.83	13.7 ± 0.96	13.0 ± 1.63	28.3 ± 3.18	29.1 ± 2.24	28.7 ± 2.80	146 ± 24.6	142 ± 5.88	144 ± 18.4
∑SFA	53.8 ± 7.32	57.4 ± 5.62	55.5 ± 6.80	60.0 ± 13.2	68.3 ± 9.37	63.9 ± 12.2	60.7 ± 10.4	65.1 ± 3.03	62.8 ± 8.14
∑MUFA	32.3 ± 6.04	31.8 ± 3.35	32.1 ± 4.95	191 ± 26.6	201 ± 16.9	197 ± 23.3	77.0 ± 15.4	77.7 ± 2.77	77.3 ± 11.3
∑PUFA	69.4 ± 10.4	75.1 ± 7.78	72.1 ± 9.68	110 ± 18.6	117 ± 4.19	113 ± 14.2	229 ± 43.0	227 ± 8.11	228 ± 31.8

[1]LF = cows fed a low-fat diet; CAN = cows fed a high-fat diet including canola seed based pelleted feed; FLX = cows fed a high-fat diet including flaxseed based pelleted feed.

[2]EE = ether extract; TDN = total digestible nutrients. TDN was calculated using the Pennsylvania-State equations (Adams, 1980). ME = kg/d of TDN × 4.409 × 0.82 (NRC, 2000). MP is calculated using the NASEM (2016) summative equation.

[3]∑SFA = sum of saturated fatty acids; ∑MUFA = sum of monounsaturated fatty acids; ∑PUFA = sum of polyunsaturated fatty acids.

The average fat (EE) consumption over the last 2 trimesters of gestation in the LF diet was 181 ± 23 g/cow/d, whereas HF diets had a fat consumption of 427 ± 34 and 419 ± 39 g/cow/d for CAN and FLX treatments, respectively. The average amount of fat (EE) provided by pelleted feed in HF diets were similar to the target of 300 g/d (309 ± 25 and 314 ± 32 g/d for CAN and FLX, respectively). Other authors, that have targeted level of fat intake from both MUFA and PUFA similar to those offered in the present study, have shown superior reproductive performance for cows receiving high PUFA levels as indicated by larger preovulatory follicles at insemination and subsequently a larger corpus luteum (Bilby et al., 2006).

Animal Performance

Performance parameters are shown in Table 4. At the start of the trial, no difference ($P \geq 0.52$) was observed among treatments for remaining days until calving, with an average of 183 d for all treatments. Also, pregnant- and CC-BW (accounting for fetal and gravid uterine weights) were not different ($P \geq 0.67$) among treatments. At the end of the second trimester (mid of trial), no effects of level ($P \geq 0.15$) and source ($P \geq 0.41$) of dietary fat were observed on pregnant-BW, CC-BW, ADG, and CC-ADG of cows over the second trimester of gestation. However, by the end of the third trimester of gestation (end of trial), LF cows tended ($P = 0.09$) to have greater cumulative ADG (0.59 vs. 0.55 kg/d) and greater ($P < 0.01$) cumulative CC-ADG (0.31 vs. 0.25 kg/d) than those of HF cows. Therefore, the CC-BW of cows fed the LF diet (708 kg) was 11 kg greater ($P = 0.04$) than that of HF (697 kg) cows. No differences ($P \geq 0.76$) were observed between CAN and FLX cows on cumulative ADG, cumulative CC-ADG, pregnant-BW, and CC-BW at the end of the third trimester of gestation.

The increase in CC-BW of cows fed the LF diet was reflected in their SCAT accretion during the feeding period. Despite no differences ($P \geq 0.44$) between LF and HF cows at the start of the trial, the proportion of cows classified as overconditioned at the end of the trial was greater ($P = 0.03$) for those fed the LF diet (13.2%) with no difference ($P = 0.84$) between CAN (3.6%) and FLX (2.9%). This is consistent with findings reported by Alexander et al. (2002) who observed that beef cows offered a low-fat supplement 59 d prior to calving had greater BCS at parturition compared with those offered high-fat supplements. Moreover, in the present study, the increased accretion of SCAT in LF cows was confirmed by ultrasound. At the start of the trial, the SCFT at the rib location of LF cows was 14% greater ($P = 0.02$) than that of HF cows (4.8 vs. 4.2 mm), and by the end of the trial, that difference increased to 21% with SCFT of cows fed LF diet remaining greater ($P < 0.01$) than that of HF cows (5.5 vs. 4.5 mm). This lower accumulation of SCAT contributed to the lighter CC-BW of HF cows by the end of pregnancy and was probably a result of differential partitioning of ME as influenced by the dietary source of energy. Although all treatments showed similar ME intakes over the course of the second and third trimesters of gestation, the portion of daily ME intake that was derived from fat was greater for the HF cows. This greater caloric intake derived from fat may have led to an increase in placental nutrient uptake which in turn could influence fetal growth. In a study using rodents, Jones et al. (2009) fed female mice either a high- or a low-fat (32% vs. 11% fat) diet over gestation and collected the placental and fetal tissues 18 d after mating. The authors reported that the high-fat diet increased the transplacental transport of glucose and neutral amino acids, and this effect was associated with an increase in protein expression of glucose transporter 1 and sodium-coupled neutral amino acid transporter 2 in microvillous plasma membranes of isolated placentas from high-fat fed dams.

The birth weights of the progeny are shown in Table 4. Calves born to cows fed HF diets during gestation were 2.6 kg heavier ($P < 0.01$) at birth than those born to cows fed the LF diet (42.9 vs. 40.2 kg), with no difference ($P = 0.24$) between calves born to cows fed CAN (42.4 kg) and FLX (43.3 kg) diets. This difference in birth weight by feeding the dam different levels of fat over gestation has been reported in lambs (Radunz et al., 2011), beef calves (Lammoglia et al., 1999; Radunz et al., 2010), and rodents (Jones et al., 2009; Strakovsky et al., 2011). In the study by Jones et al. (2009), they reported a 43% increase in the weight of mice fetuses from high-fat fed dams at day 18 of gestation. This increase in fetal weight was attributed to the increased placental uptake of nutrients due to feeding the high-fat diet as discussed previously. In the present study, it is likely that HF diets prepartum increased placental nutrient uptake which resulted in heavier calves at birth.

When birth weight data were analyzed separately for bull and heifer calves, sex-specific effects

Table 4. Effects of level and source of fat in the diet of pregnant beef cows during the second and third trimesters of gestation on prepartum performance of the dam and birth weight of the progeny

	Treatments[1]				Contrasts[2]	
	LF	CAN	FLX	SEM	LF vs. HF	CAN vs. FLX
Item[3]	(n = 10)	(n = 10)	(n = 10)			
Start of trial						
Days until calving, d	183	183	184	2.02	0.87	0.52
BW, kg	664	662	664	19.1	0.79	0.67
CC-BW, kg	659	657	658	19.0	0.72	0.69
BCS	2.65	2.59	2.63	0.04	0.37	0.46
Thin, % of cows	0.0	0.0	0.0	—	—	—
Optimal, % of cows	98.2	97.8	93.3	2.87	0.44	0.10
Overconditioned, % of cows	1.8	2.2	6.7	2.73	0.50	0.28
SCFT						
Rib, mm	4.8	4.1	4.4	0.20	0.03	0.34
Rump, mm	4.7	4.9	4.5	0.30	0.99	0.32
Mid of trial						
Days until calving, d	99	99	100	2.02	0.87	0.52
BW, kg	711	707	706	5.90	0.37	0.84
ADG, kg/d	0.57	0.55	0.51	0.17	0.27	0.45
CC-BW, kg	693	688	687	5.45	0.25	0.78
CC-ADG, kg/d	0.41	0.38	0.34	0.18	0.15	0.41
End of trial						
Days until calving, d	23	23	24	1.49	0.87	0.51
BW, kg	758	751	752	4.44	0.19	0.87
Cumulative ADG, kg/d	0.59	0.55	0.55	0.11	0.09	0.88
CC-BW, kg	708	697	697	4.07	0.04	0.98
Cumulative CC-ADG, kg/d	0.31	0.25	0.24	0.12	<0.01	0.76
BCS	2.80	2.64	2.68	0.12	0.01	0.52
Change	0.13	0.05	0.04	0.12	0.12	0.96
Thin, % of cows	0.0	0.0	0.0	—	—	—
Optimal, % of cows	86.8	96.4	97.1	7.55	0.03	0.84
Overconditioned, % of cows	13.2	3.6	2.9	7.55	0.03	0.84
SCFT						
Rib, mm	5.5	4.2	4.8	0.36	<0.01	0.14
Change, mm	0.7	0.1	0.4	0.39	0.15	0.48
Rump, mm	5.7	5.0	5.5	0.32	0.25	0.26
Change, mm	1.0	0.0	1.0	0.35	0.25	0.06
Birth weight of calves						
All calves, kg	40.2	42.4	43.3	1.08	<0.01	0.24
Bull calves, kg	41.4	44.6	45.2	1.08	<0.01	0.68
Heifer calves, kg	39.0	40.5	41.0	1.65	0.20	0.73

[1]LF = low-fat diet; CAN = high-fat diet including canola seed-based pelleted feed; FLX = high-fat diet including flaxseed-based pelleted feed.

[2]HF = average of CAN and FLX.

[3]CC-BW = BW corrected for conceptus (NRC, 2000); CC-ADG = ADG based on conceptus corrected BW; cumulative ADG = ADG from the start of trial; thin = BCS < 2.5; optimal = 2.5 ≤ BCS ≤ 3.0; overconditioned = BCS > 3.0; SCFT = subcutaneous fat thickness.

were observed. Bull calves born to cows fed HF diets were 3.4 kg heavier (P < 0.01) at birth than those from cows fed LF diet (44.9 vs. 41.4 kg), with no difference (P = 0.68) observed between bull calves born to cows fed CAN (44.6 kg) and FLX (45.2 kg) diets. On the other hand, no difference (P ≥ 0.20) was observed among treatments on birth weight of heifer calves, with an average of 40.2 kg across treatments. Similar sex-specific effects on BW of the progeny have been reported by Micke et al. (2010) after beef heifers were fed a low or a high CP diet during early gestation and midgestation. However, the reason for this sex-specific effect of feeding HF diets during gestation on fetal growth is not clear. Studies using rodents suggest that the placenta of female fetuses is capable of adjusting

and become more efficient in nutrient transport in the presence of dietary changes (Penaloza et al., 2009; Rosenfeld, 2015). This diet dependent adaptation capacity of the placenta of female fetuses has been attributed to sexual dimorphism in placental DNA methylation (Gallou-Kabani et al., 2010; Mao et al., 2010; Gabory et al., 2012). After feeding pregnant mice with a high- or a low-fat (60% vs. 10% fat) diet over gestation and collecting the placental and fetal tissue at 15 d of gestation, Gallou-Kabani et al. (2010) found that efficiency of the placenta, measured as the ratio of fetal to placental weight, was greater for female fetuses than those from male fetuses when the low-fat diet was fed. Such increased placenta efficiency could help explain the differential response of male and female calves in the present study to prepartum fat supplementation.

Fatty Acid Profiles

The fatty acid profiles of the SCAT are shown in Tables 5 and 6. At the start of the feeding period, no major differences were found with the only difference being the lower ($P = 0.04$) total PUFA level of FLX (1.14% vs. 1.29%) compared with CAN and LF cows. However, at the end of the feeding period, the total PUFA proportion of FLX cows (2.23%) tended ($P = 0.09$) to be greater than those of CAN (1.76%) and LF (1.58%) cows. Also, the total proportion of n-3 in SCAT of FLX cows (0.58%) was greater ($P \leq 0.01$) than that of LF and CAN cows (0.38% and 0.37%, respectively). This is consistent with the findings reported by He et al. (2012) where, compared with no flaxseed inclusion, a 15% (DM basis) inclusion of ground flaxseed in the diet of beef cows increased their total PUFA and n-3 fatty acid concentrations in subcutaneous adipose tissue. According to Kouba and Mourot (2011), including flaxseed in the diet of ruminants results in an increase in the n-3 fatty acid content in the animal product. The proportion of α-linolenic acid in SCAT of FLX cows (0.52%) was greater ($P < 0.01$) than that of LF and CAN cows (0.33% and 0.32%, respectively). This can be explained by a greater amount of α-linolenic acid by-passing the rumen in FLX cows because it has been suggested that increasing the ruminal concentration of this fatty acid reduces its rate of biohydrogenation in the rumen (Beam et al., 2000; Vahmani et al., 2017). No differences ($P \geq 0.11$) were observed among treatments in the proportion of total and individual n-6 fatty acids. Also, feeding the FLX diet over gestation resulted in a greater ($P < 0.01$) total proportion of biohydrogenation intermediates such as conjugated linolenic acid (**CLnA**), CLA, and atypical dienes (**AD**) in the SCAT of FLX cows. This greater proportion of CLnA, CLA, and AD in SCAT of FLX cows is most likely the result of these intermediates leaving the rumen before complete biohydrogenation of substrates such as α-linolenic acid (Shingfield et al., 2013; Vahmani et al., 2016b). Among the CLA isomers, *c*9,*t*11-18:2 represented 90.0%, 90.9%, and 87.6% of the total CLA in SCAT of LF, CAN, and FLX, respectively. This is consistent with *c*9,*t*11-18:2 being the major isomer found in ruminant fat (Bauman et al., 2000).

The total proportions of MUFA, branched-chain fatty acids (BCFA), and SFA in SCAT were not different ($P \geq 0.30$) among treatments at the start of the trial (Table 6). However, by the end of the third trimester of gestation, the total proportion of MUFA was greater ($P = 0.03$) in LF (57.5%) cows than in HF cows and greater ($P < 0.01$) in CAN (56.7%) cows than in FLX (53.5%) cows. When analyzing the MUFA fractions (*cis* and *trans*) separately, it was found that the proportions of all *t*-MUFA isomers in SCAT of LF cows were lower ($P < 0.01$) than those of HF cows, with vaccenic acid (*t*11-18:1) being the most abundant among all *t*-MUFA isomers representing 47.1%, 41.9%, and 49.1% for LF, CAN, and FLX, respectively. It is known that when ruminants are fed diets with a low concentrate to forage ratio, *t*11-18:1 is the major *t*-MUFA isomer (Madron et al., 2002; Dugan et al., 2007). Conversely, the total proportion of *c*-MUFA and all respective isomers in SCAT of LF cows were greater ($P < 0.01$) or tended ($P \leq 0.09$) to be greater than those of HF cows. Oleic acid (*c*9-18:1) proportions were 73.9%, 75.7%, and 77.8% for LF, CAN, and FLX, respectively, and were the most abundant among all *c*-MUFA isomers. This is consistent with findings reported by Dugan et al. (2007) for SCAT of finished beef cattle with a 73% barley grain diet. Also, the total proportion of *c*-MUFA in SCAT of FLX cows (50.4%) was lower ($P < 0.01$) than that of CAN cows (54.0%). This lower proportion of *c*-MUFA in SCAT of FLX cows is most likely due to the increase in dietary PUFAs leading to a decrease in the rate of biohydrogenation or a decrease in Δ-9 desaturase activity in adipose tissue (Shingfield et al., 2013; Mapiye et al., 2014).

At the end of the third trimester of gestation, the total proportion of SFA in SCAT tended ($P = 0.05$) to be greater for FLX compared with CAN cows, whereas no difference ($P = 0.20$) was observed between LF and HF cows. Among the SFA, the proportion of palmitic acid (16:0) was greater

Table 5. Effects of level and source of fat in the diet of pregnant beef cows during the second and trimesters of gestation on PUFA profiles in subcutaneous adipose tissue of the dam

	Treatments[1]				Contrasts[2]	
	LF	CAN	FLX	SEM	LF vs. HF	CAN vs. FLX
Fatty acid, % of total)[3]	(n = 10)	(n = 10)	(n = 10)			
Start of trial						
ΣPUFA	1.29	1.29	1.14	0.08	0.16	0.04
Σn-3	0.50	0.49	0.44	0.07	0.39	0.16
18:3n-3	0.44	0.43	0.39	0.06	0.37	0.34
22:5n-3	0.04	0.04	0.03	0.01	0.81	0.07
Σn-6	0.80	0.79	0.70	0.04	0.26	0.09
18:2n-6	0.73	0.72	0.63	0.04	0.19	0.08
20:4n-6	0.03	0.03	0.03	0.01	0.87	0.93
ΣCLnA	0.06	0.08	0.06	0.01	0.16	0.16
*c*9,*t*11,*t*15-18:3	0.05	0.06	0.05	0.01	0.29	0.45
*c*9,*t*11,*c*15-18:3	0.01	0.02	0.01	0.00	0.21	0.07
ΣCLA	0.94	0.99	0.89	0.16	0.99	0.46
*c*9,*t*11- + *t*7,*c*9-18:2	0.84	0.88	0.79	0.15	0.91	0.47
*t*11,*c*13-18:2	0.04	0.04	0.04	0.01	0.63	0.78
t,*t*-CLA	0.06	0.06	0.06	0.01	0.64	0.23
ΣAD	0.55	0.61	0.55	0.09	0.76	0.52
*c*9,*t*14- + *c*9,*t*13-18:2	0.21	0.24	0.20	0.05	0.84	0.40
*c*9,*t*15-18:2	0.07	0.09	0.07	0.03	0.68	0.30
*t*11,*c*15-18:2	0.22	0.23	0.23	0.03	0.82	0.91
End of trial						
ΣPUFA	1.58	1.76	2.23	0.63	0.09	<0.10
Σn-3	0.38	0.37	0.58	0.03	0.01	<0.01
18:3n-3	0.33	0.32	0.52	0.02	<0.01	<0.01
22:5n-3	0.05	0.05	0.06	0.01	0.35	0.13
Σn-6	1.20	1.39	1.65	0.60	0.13	0.28
18:2n-6	1.10	1.29	1.53	0.56	0.11	0.26
20:4n-6	0.05	0.07	0.08	0.04	0.68	0.69
ΣCLnA	0.05	0.05	0.12	0.02	<0.01	<0.01
*c*9,*t*11,*t*15-18:3	0.03	0.03	0.06	0.01	<0.01	<0.01
*c*9,*t*11,*c*15-18:3	0.02	0.02	0.06	0.01	<0.01	<0.01
ΣCLA	0.70	0.88	1.05	0.22	<0.01	0.09
*c*9,*t*11- + *t*7,*c*9-18:2	0.63	0.80	0.92	0.19	<0.01	0.20
*t*11,*c*13-18:2	0.03	0.03	0.07	0.01	0.01	<0.01
t,*t*-CLA	0.04	0.05	0.07	0.02	<0.01	0.01
ΣAD	0.40	0.57	0.90	0.22	<0.01	<0.01
*c*9,*t*14- + *c*9,*t*13-18:2	0.16	0.25	0.34	0.08	<0.01	0.05
*c*9,*t*15-18:2	0.08	0.11	0.15	0.04	<0.01	<0.01
*t*11,*c*15-18:2	0.12	0.12	0.32	0.08	<0.01	<0.01

[1]LF = low-fat diet; CAN = high-fat diet including canola seed-based pelleted feed; FLX = high-fat diet including flaxseed-based pelleted feed.

[2]HF = average of CAN and FLX.

[3]*c* = cis; *t* = trans; ΣPUFA = sum of polyunsaturated fatty acids (Σn-6 + Σn-3); Σn-3 = sum of n-3 fatty acids; Σn-6 = sum of n-6 fatty acids; ΣCLnA = sum of conjugated linolenic acids; ΣAD = sum of atypical dienes; ΣCLA = sum of conjugated linoleic acids.

(P < 0.01) for LF cows than for HF cows. This could be attributed to the fact that proportion of 16:0 was greater in the LF diet, as well as to greater de novo fatty acid synthesis because 16:0 is the final product of this process (Shingfield et al., 2013). However, the proportion of stearic acid (18:0) was lower (P < 0.01) and those of myristic (14:0) and pentadecanoic (15:0) acids tended (P = 0.08) to be lower for LF cows compared with HF cows. The lower proportion of 18:0 in SCAT of LF could be attributed to 2 reasons. First, fewer amounts of dietary *c*9-18:1 and 18:3n-3 going through complete biohydrogenation because the proportions of these fatty acids were lower in LF diet than in HF diet. Also, the lower 18:0 and greater of *c*9-18:1 proportion in SCAT of LF cows could be due to

Table 6. Effects of level and source of fat in the diet of pregnant beef cows during the second and third trimesters of gestation on monounsaturated and saturated fatty acid profiles in subcutaneous adipose tissue of the dam

	Treatments[1]				Contrasts[2]	
	LF	CAN	FLX	SEM	LF vs. HF	CAN vs. FLX
Fatty acid, % of total[3]	(n = 10)	(n = 10)	(n = 10)			
Start of trial						
ΣMUFA	53.9	52.7	52.0	2.63	0.30	0.68
Σ*t*-MUFA	2.37	2.73	2.64	0.27	0.31	0.79
*t*9-18:1	0.26	0.27	0.25	0.05	0.97	0.55
*t*10-18:1	0.20	0.21	0.19	0.03	0.96	0.48
*t*11-18:1	1.24	1.46	1.45	0.14	0.23	0.96
*t*13-*t*14-18:1	0.28	0.36	0.33	0.04	0.14	0.57
Σ*c*-MUFA	51.6	50.0	49.3	2.50	0.25	0.74
*c*9-14:1	1.23	1.10	1.42	0.10	0.81	0.05
*c*9-16:1	5.84	4.99	4.91	0.46	0.10	0.88
*c*9-17:1	1.13	1.03	1.07	0.09	0.24	0.61
*c*9-18:1	40.0	39.7	39.1	1.79	0.58	0.60
*c*11-18:1	1.58	1.39	1.24	0.12	0.06	0.34
ΣBCFA	3.18	3.27	3.25	0.15	0.63	0.94
ΣSFA	40.0	41.1	42.1	2.84	0.32	0.56
14:0	3.27	2.96	3.36	0.39	0.64	0.15
15:0	0.58	0.56	0.61	0.03	0.82	0.21
16:0	24.8	24.9	25.1	1.27	0.85	0.78
17:0	1.11	1.15	1.25	0.09	0.21	0.19
18:0	9.91	11.2	11.5	1.19	0.15	0.77
End of trial						
ΣMUFA	57.5	56.7	53.5	1.59	0.03	<0.01
Σ*t*-MUFA	1.53	2.72	3.16	1.03	<0.01	0.14
*t*9-18:1	0.22	0.36	0.29	0.06	<0.01	0.01
*t*10-18:1	0.14	0.28	0.25	0.07	<0.01	0.36
*t*11-18:1	0.72	1.14	1.55	0.49	<0.01	<0.01
*t*13-*t*14-18:1	0.20	0.34	0.45	0.17	<0.01	0.22
Σ*c*-MUFA	55.9	54.0	50.4	2.56	<0.01	<0.01
*c*9-14:1	1.66	1.58	1.22	0.12	0.08	0.04
*c*9-16:1	7.79	6.89	5.63	1.13	<0.01	0.03
*c*9-17:1	1.04	0.90	0.86	0.18	<0.01	0.39
*c*9-18:1	41.3	40.9	39.2	1.04	0.09	0.05
*c*11-18:1	2.30	1.95	1.70	0.58	<0.01	0.03
ΣBCFA	2.58	2.66	2.82	0.89	0.16	0.22
ΣSFA	37.2	37.3	39.4	0.92	0.20	0.05
14:0	2.74	3.10	3.37	0.21	0.06	0.39
15:0	0.48	0.52	0.55	0.17	0.04	0.37
16:0	26.0	24.0	23.9	1.54	<0.01	0.77
17:0	0.83	0.80	0.87	0.23	0.95	0.03
18:0	6.97	8.61	9.93	1.97	<0.01	0.07

[1]LF = low-fat diet; CAN = high-fat diet including canola seed-based pelleted feed; FLX = high-fat diet including flaxseed-based pelleted feed.

[2]HF = average of CAN and FLX.

[3]*c* = cis; *t* = trans; ΣMUFA = sum of monounsaturated fatty acids; Σ*c*-MUFA = sum of *cis*-monounsaturated fatty acids; Σ*t*-MUFA = sum of *trans*-18:1 isomers; ΣBCFA = sum of branched-chain fatty acids; ΣSFA =sum of saturated fatty acids.

a greater Δ-9 desaturase activity at the tissue level as suggested by Mapiye et al. (2014). Also, because de novo fatty acid synthesis was probably greater in LF cows (as discussed previously), it supports the hypothesis of a greater Δ-9 desaturase activity in adipose tissue of this group of cows. According to Smith et al. (2006), desaturase gene expression is highly expressed during de novo fatty acid synthesis.

The above data provide evidence that prepartum fat supplementation and in particular the fatty acid make-up of the supplemental fat influence the fatty acid profile of subcutaneous adipose tissue. Sources high in PUFA will lead to adipose tissue with a greater degree of PUFA, whereas those high in MUFA will lead to adipose tissue with higher levels of MUFA. With respect to our hypothesis, this data also show that our experimental model (i.e., feeding a canola or flax-based pellet prepartum) was successful in manipulating the source and nature of dietary energy fed to pregnant beef cows. This conformation is important in helping to explain not only the results of the current trial but also the results of our companion paper (Añez-Osuna et al., unpublished data).

Blood Metabolites

The serum NEFA and BHBA concentrations of cows are shown in Table 7. No differences ($P \geq 0.35$) were observed among treatments for serum NEFA or BHBA concentrations of cows at the start of the trial. By the end of the third trimester of gestation, the serum NEFA concentration of cows fed HF diets was 206 μEq/L greater ($P < 0.01$) compared with those fed LF (592 μEq/L). This greater serum NEFA concentration in HF cows can be attributed to a greater adipose tissue mobilization at the time of sampling as evidenced by their lower SCAT accretion compared with LF cows (as discussed previously), and their change in CC-BW during the previous 14 d. Conceptus-corrected BW of cows at the time of blood sample collection (23 d prepartum) and those recorded 14 d previously (data not shown) indicated a loss in CC-BW across all treatments. Statistical comparison of the change in CC-BW occurring during this period showed that HF cows had greater ($P < 0.01$; SEM = 1.67) loss in CC-BW than LF cows (−7.0 vs. −2.1 kg), and the loss in CC-BW of FLX cows tended ($P = 0.07$; SEM = 1.93) to be greater than that of CAN cows (−8.8 vs. −5.2 kg). Also, the fact that HF cows were gestating heavier calves also helps to explain their increased serum NEFA levels compared with LF cows.

Table 7. Effects of level and source of fat in the diet of pregnant beef cows during the second and third trimesters of gestation on concentration of blood serum NEFA and β-hydroxy butyrate of the dam

	Treatment[1]				Contrasts[2]	
	LF	CAN	FLX	SEM	LF vs. HF	CAN vs. FLX
Item	(n = 10)	(n = 10)	(n = 10)			
Start of trial						
Days until calving, d	183	182	192	4.67	0.47	0.15
NEFA, µEq/L	581	601	574	157	0.92	0.72
BHBA[3], mg/dL	13.7	12.6	11.4	1.78	0.35	0.55
End of trial						
Days until calving, d	22	22	23	2.80	0.78	0.94
NEFA, µEq/L	592	636	961	56.9	<0.01	<0.01
BHBA, mg/dL	9.75	10.2	8.96	0.96	0.78	0.13

[1]LF = low-fat diet; CAN = high-fat diet including canola seed-based pelleted feed; FLX = high-fat diet including flaxseed-based pelleted feed.
[2]HF = average of CAN and FLX.
[3]BHBA = β-hydroxy butyrate.

Reid and Hinks (1962) found that plasma NEFA concentration of late pregnancy ewes was positively and highly correlated with total fetal weight. Finally, the greater fat content in HF diet could have increased the serum NEFA concentration in these cows. Fat inclusion in the diet of dry dairy cows during the prepartum period has been shown to increase their serum NEFA concentration (Leroy et al., 2014). The reason for this increase in NEFA due to dietary fat inclusion has been attributed to an incomplete uptake of free fatty acids by adipose tissue (Grummer and Carroll, 1991; Chilliard, 1993).

Serum NEFA concentration of cows fed FLX (961 µEq/L) was greater (P < 0.01) than those fed CAN (636 µEq/L). In general, it has been suggested that high PUFA diets increase blood NEFA concentration in ruminants (Bowden, 1971; Chilliard, 1993). However, in the present study, the greater serum NEFA concentration of FLX compared with CAN cows was most likely due to a greater adipose tissue mobilization as evidenced by the greater loss in CC-BW previously mentioned. The greater BW loss of FLX compared with CAN cows can be attributed to a reduced short-chain fatty acid production as a result of a decrease in ruminal fermentation. It is well documented that the addition of fat to the diets of ruminants negatively affects the fermentation of structural carbohydrates causing a reduction in short-chain fatty acid production (Jenkins, 1993). This negative effect on fiber fermentation increases with the degree of fatty acid unsaturation (Jenkins et al., 2008; Buccioni et al., 2012). Also, a greater placental uptake of PUFA could have increased the demand for adipose tissue mobilization, hence increasing NEFA circulation in FLX cows. Along with triglycerides, circulating NEFA are the main source of fatty acid uptake by the placenta (Lager and Powell, 2012). Moreover, fetal requirements for linoleic and α-linolenic acid and their associated long-chained PUFA increase by the end of gestation, and both placental and fetal tissues have been shown to have a preferential uptake of these fatty acids by the end of gestation (Herrera, 2002; Jones et al., 2007). Therefore, the fatty acids mobilized by FLX cows in the form of NEFA by the end of gestation were most probably PUFA and α-linolenic acid because the total proportion of these were greater in the SCAT of FLX. No differences (P ≥ 0.13) were observed among treatments for serum BHBA concentration by the end of the third trimester of gestation.

CONCLUSIONS

Feeding a low-fat diet to beef cows during gestation resulted in an increase in BCS and subcutaneous fat thickness. Moreover, when the BW of cows was corrected for fetal and gravid uterine weight, cows fed the low-fat diet were heavier than those fed the high-fat diets, and the extra weight gain was in part a result of subcutaneous fat accretion. In contrast, feeding high-fat diets during gestation resulted in leaner cows and heavier calves at birth. Also, the type of dietary fatty acid during gestation influenced the fatty acid profile in subcutaneous adipose tissue and NEFA concentration in blood serum of cows. Dams receiving a diet high in PUFAs during gestation showed a greater proportion of CLA, CLnA, and 18:3n-3 fatty acids in their subcutaneous adipose tissue and greater level of serum NEFAs by the end of gestation.

In conclusion, these results suggest that ME partitioning in gestating beef cows is influenced by level and source of dietary fat. Also, these results suggest that a high-fat diet over gestation increases the placental nutrient uptake, resulting in heavier calves at birth.

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