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Effect of dietary fat concentration from condensed corn distillers' solubles, during the growing phase, on beef cattle performance, carcass traits, digestibility, and ruminal metabolism

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ABSTRACT: The objectives of this study were to determine the effect of fat concentration from corn distillers' solubles (CDS), fed during the growing phase, on DMI, gain, carcass traits, digestibility, ruminal metabolism, and methane emissions of steers. In Exp. 1, 40 steers (age = 136 ± 20 d; BW = 185 ± 11 kg) were randomly allotted to 1 of 5 dietary treatments: 1) a corn-based growing diet (CNT), 2) 0% CDS, 3) 10% CDS, 4) 19% CDS, or 5) 27% CDS. Diets 2 through 5 included coproducts (corn gluten feed and soybean hulls) and were formulated to achieve fat concentrations of 3, 5, 7, and 9%, respectively. Diets were fed once daily for 106 d (growing phase). All steers were fed a corn-based diet from d 107 to 196. Contrasts were used to examine 1) the difference between CNT and 10% CDS and 2) linear and quadratic effects of CDS inclusion. During the growing phase, steers fed CNT had increased ($P < 0.01$) ADG and G:F compared with steers fed 10% CDS. Increasing CDS inclusion increased (linear, $P \leq 0.02$) ADG and G:F. Overall, steers fed CNT had increased ($P < 0.01$) ADG compared with steers fed 10% CDS, but increasing CDS inclusion had no effect ($P = 0.19$) on overall ADG. Overall DMI and G:F were not different ($P \geq 0.16$) in any contrast. There was a trend (Linear; $P = 0.08$) for ultrasound marbling at d 196 to increase as CDS inclusion increased; however, there were no effects ($P \geq 0.20$) of treatment on carcass marbling or quality grade. In Exp. 2, 5 steers (BW = 335 ± 56 kg) were fed Exp. 1 diets for ad libitum intakes in a 5 × 5 Latin square design. Apparent DM digestibility increased (linear, $P = 0.02$) with increasing dietary CDS inclusion. Steers fed CNT had greater ($P = 0.01$) DM digestibility than those fed 10% CDS. Fat digestibility increased (linear, $P < 0.01$) in steers with increasing CDS, but NDF and ADF digestibility were not affected ($P \geq 0.17$) by treatment. Similarly, ruminal pH and VFA concentrations were not affected ($P \geq 0.13$). Also, there was no difference ($P \geq 0.37$) in ruminal methane emissions (g/h). In conclusion, feeding corn during the growing phase increased overall ADG compared with 10% CDS coproduct-based diet but did not affect carcass traits or methane production. Increasing dietary fat inclusion from CDS in coproduct-based diets linearly increased DM and fat digestibility and predicted marbling scores via ultrasound but did not affect marbling at slaughter, NDF digestibility, propionate, or methane production.

Key words: beef calves, dietary fat, methane production, rumen metabolism

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INTRODUCTION

Recently, it has been found that early-weaned calves fed growing diets that include distillers' grains and other coproducts produce carcasses with marbling scores similar to those fed starch-based diets (Retallick et al., 2010; Meteer et al., 2012; Segers et al., 2014). It is possible that increased dietary fat in some coproducts may be sufficient to improve marbling score and subsequent USDA quality grade (Segers et al., 2014). The ability of dietary fat to shift ruminal fermentation

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toward propionate production is a possible mechanism that may help explain the similar marbling scores observed in carcasses from calves fed coproducts and those fed starch-based diets during the growing phase (Chalupa et al., 1986; Retallick et al., 2010; Meteer et al., 2012; Segers et al., 2014). Condensed corn distillers' solubles (**CDS**) are a liquid coproduct from the ethanol industry. Lardy (2007) reported fat concentrations in CDS ranging from 9 to 15%, but fat concentrations can exceed 18%, dependent on source (Pesta et al., 2012). The increased availability of CDS in the Midwest makes this ingredient a useful option for inclusion in a variety of cattle feeding strategies such as the development of early-weaned calves; therefore, it is important to understand the effect of this ingredient in the rumen as well as how it impacts compositional development and subsequent carcass characteristics. The objectives of these experiments were to evaluate performance, carcass traits, ruminal metabolism, methane production, and nutrient digestibility associated with feeding either corn-based diets or coproduct-based diets with increasing levels fat from CDS. The hypotheses were that calves fed corn-based growing rations would exhibit increased performance compared with calves fed coproducts with 10% CDS inclusion and that increased inclusion of CDS in the diet would increase marbling score and decrease ruminal methane production without sacrificing animal performance.

MATERIALS AND METHODS

Experiment 1

Animal and Diet Management. Forty crossbred steers (BW = 185 ± 11 kg) were weaned (age = 136 ± 20 d) at the University of Illinois Beef Cattle and Sheep Field Research Laboratory in Urbana, IL. Calves were managed according to the guidelines recommended in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 2010). All experimental procedures were approved by the University of Illinois Institutional Animal Care and Use Committee.

Calves were castrated 21 d before weaning. At castration, calves were given penicillin (Pen Ject; Bimeda, Inc., Irwindale, CA) and vaccinated for clostridial diseases (i.e., *Clostridium chauvoei*, *Clostridium septicum*, *Clostridium haemolyticum*, *Clostridium novyi* Type B, *Clostridium tetani*, and *Clostridium perfringens* types C and D) using Covexin 8 (Schering-Plough Animal Health Corp., Omaha, NE) and for bovine pneumonia (*Mannheimia* (*pasteurella*) *haemolytica* type A1) using One Shot Ultra 7 (Pfizer Inc., Kalamazoo, MI). Calves were also vaccinated for infectious bovine rhinotracheitis, bovine viral diarrhea Types 1 and 2, parainfluenza-3, and bovine respiratory syncytial virus using Bovi-Shield Gold Finishing Phase 5 L5 HB (Pfizer Inc., New York, NY). Finally, calves were vaccinated against *Mycoplasma bovis* using Pulmo-Guard MpB (American Animal Health, Inc., Grand Prairie, TX). Calves were vaccinated again at weaning using the previously described regimen with an additional vaccine for the prevention of bovine respiratory disease (INFORCE 3; Zoetis, Kalamazoo, MI). Deworming was accomplished via transdermal eprinomectin (IVOMEC EPRINEX; Merial Ltd., Duluth, GA). Calves were implanted at the initiation of the experiment with 100 mg progesterone, 10 mg estradiol benzoate, and 29 mg tylosin tartrate (Component E-C; Ivy Animal Health, Overland Park, KS) and again at d 106 with 24 mg estradiol (Compudose; Ivy Animal Health).

At the initiation of the growing phase, BW measurements were collected before feeding on 2 consecutive days and averaged to calculate initial BW. Calves (BW = 185 ± 11 kg) were then randomly assigned to 5 pens (pen = 8 animals) and housed in a barn constructed of a wood frame with a ribbed metal roof and with siding on the north, west, and east sides. The south side of the barn was covered with polyvinyl chloride–coated 1.27 by 1.27 cm wire mesh bird screen and equipped with retractable curtains for wind protection. Within the barn, calves were housed in 4.88- by 4.88-m pens (8 calves per pen) constructed of 5.08-cm galvanized steel tubing. Pens had slatted concrete floors covered by interlocking rubber matting. Diets were fed using the GrowSafe (GrowSafe Systems Ltd., Airdrie, AB Canada), which continuously monitored and recorded feed consumption on an individual basis. Animal weights were collected in a hydraulic chute (Flying W, Inc., Watonga, OK) and recorded using digital livestock scales (TRU-TEST XR3000; Tru Test Inc., Mineral Wells, TX).

Pens were randomly assigned to 1 of 5 experimental growing diets: 1) a corn-based growing diet (**CNT**), 2) 0% CDS, 3) 10% CDS, 4) 19% CDS, or 5) 27% CDS (Table 1). In addition to CDS, diets 2 to 5 included corn gluten feed and soybean hulls formulated to achieve fat concentrations of 3, 5, 7, and 9%, respectively. Both the CNT and common diets were formulated to contain 5.0% fat. Diets were delivered to pens once daily for 106 d (growing phase) and were fed for ad libitum intakes. All steers were then fed a corn-based diet from d 107 to 196 (finishing phase). Final BW, hip height, and ultrasound measurements were collected on d 196.

Sampling and Analysis. Feed ingredients were collected every 35 d, between the initiation and conclusion of the experiment. Composited feed samples were freeze-dried (FreeZone[12]; Labconco Corp., Kansas City, MO) and then ground using a Wiley mill (1-mm screen; Arthur H. Thomas, Philadelphia, PA). All samples were

Table 1. Dry matter composition and nutrient analysis of diets offered to early-weaned calves and fistulated steers fed corn or coproduct blends with increasing concentrations of fat from condensed corn distillers' solubles (CDS) in Exp. 1 and 2

	Growing diet[1]					
		CDS inclusion				Finishing
Item	CNT	0%	10%	19%	27%	diet
Ingredient, % DM						
Corn silage	20.0	20.0	20.0	20.0	20.0	20.0
Cracked corn	52.0	–	–	–	–	45.0
Soybean hulls	–	25.0	25.0	25.0	25.0	–
DDGS[2]	18.0	–	–	–	–	–
WDGS[3]	–	–	–	–	–	25.0
Dry corn gluten feed	–	45.0	35.0	26.0	18.0	–
Condensed distillers' solubles	–	–	10.0	19.0	27.0	–
Supplement, % diet DM						
Ground corn	5.50	7.30	7.30	7.30	7.30	7.30
Urea	1.60	–	–	–	–	–
Limestone	2.70	2.50	2.50	2.50	2.50	2.50
Trace mineral salt[4]	0.10	0.10	0.10	0.10	0.10	0.10
Rumensin 90[5]	0.02	0.017	0.017	0.017	0.017	0.017
Tylan 40[6]	0.01	0.011	0.011	0.011	0.011	0.011
Liquid fat	0.07	0.075	0.075	0.075	0.075	0.075
Composition, % DM						
DM	67.7	77.5	73.0	68.9	65.2	67.7
CP	14.0	16.9	16.3	15.8	15.3	14.0
NDF	22.8	43.3	40.3	37.7	35.3	22.8
ADF	12.0	24.5	23.2	22.2	21.2	13.3
Ether extract	5.3	1.8	4.4	6.8	8.9	5.3
Ca	0.95	1.47	1.48	1.48	1.49	1.37
P	0.40	0.61	0.65	0.68	0.71	0.56
S	0.23	0.34	0.41	0.47	0.53	0.20
Ash	5.2	7.0	7.5	7.9	8.3	5.8
NEm, Mcal/kg[7]	1.77	1.68	1.63	1.72	1.75	1.53
NEg, Mcal/kg[8]	1.15	1.07	1.02	1.10	1.13	0.94

[1]CNT = corn-based growing diet. Growing phase diets for feedlot study (Exp. 1) were also experimental diets for metabolism study (Exp. 2).

[2]DDGS = dried distillers' grains with solubles: 0.74% S, 39.3% NDF, and 26.8% CP.

[3]WDGS = wet distillers' grains with solubles: 29.7% DM, 0.40% S, 40.0% NDF, and 29.7% CP.

[4]Trace mineral salt contains 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KC_{l2}), 10% S (as S8 prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 [Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN]), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 mg/kg Co (as Availa-4), 250 I (as Ca(IO3)2), 150 mg/kg Se (Na_2SeO_3), 2,205 kIU/kg vitamin A (as retinyl acetate), 662.5 kIU/kg vitamin D (as cholecalciferol), 22,047.5 IU/kg vitamin E (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, and salt.

[5]Rumensin; 198 g/kg (Elanco Animal Health, Greenfield, IN).

[6]Tylosin; 88 g/kg (Elanco Animal Health).

[7]Calculated based on BW and DMI of growing cattle using equations from NRC (1996).

[8]Calculated based on BW and DMI of growing cattle using equations from NRC (1996).

analyzed for DM (24 h at 100°C). All freeze-dried samples were subjected to perchloric acid digestion and inductively coupled plasma atomic emission spectroscopy analysis of complete minerals (method 975.03; AOAC, 1988). Freeze-dried samples were analyzed for ADF and NDF (using Ankom Technology method 5 and 6, respectively; Ankom200 Fiber Analyzer; Ankom Technology, Macedon, NY), CP (Leco TruMac; LECO Corporation, St. Joseph, MI), fat (ether extract method; Ankom Technology), and total ash (500°C for 12 h, HotPack Muffle Oven model 770750; HotPack Corp., Philadelphia, PA). Ingredients were individually analyzed for nutrient composition, and the resulting values were used to calculate nutrient composition of the diets.

Ultrasound Data. Ultrasound measurements for 12th rib back fat thickness (**BF**) and marbling score (**MS**) were collected on d 106 and 196 by a trained technician from the University of Illinois. The ultrasound system included an Aloka SSD-500V equipped with a 12.5-cm 3.5-MHz transducer (Aloka Co. Ltd., Wallingford, CT). Soybean oil was used as a sound wave focusing medium. Ultrasound images were captured and measured using

Cattle Performance Enhancement Company ultrasound image software (Cattle Performance Enhancement Co., LLC, Oakley, KS). Ultrasound images were collected on the animal's right side parallel to the spinal column and perpendicular to the 11th, 12th, and 13th ribs, halfway between the axial and transverse processes of the lumbar vertebrae. The ultrasound location was clipped free of hair and curried clean before image collection.

Carcass Data Collection. On d 196, cattle were sold and shipped 296.1 km to a commercial slaughter facility (Joslin, IL). Cattle were humanely slaughtered under USDA inspection. Immediately after harvest, HCW was collected. Carcasses were then chilled for 24 h at –4°C. At approximately 24 h postmortem, the right side of the carcass was ribbed between the 12th and 13th ribs and carcass data including LM area, BF, MS, and percent KPH were collected by plant personnel using video image analysis (VBS2000; E+V Technology GmbH, Oranienburg, Germany). University of Illinois trained personnel recorded measurements and determined quality grade and yield grade. The equation 2.5 + 0.984 × (cm of BF) + 0.20 × (% KPH) + 0.0084 × (kg of HCW) – 0.0497 × (LM area in cm2) was used to calculate yield grade (Field, 2007).

Statistical Analysis. The experiment used a completely randomized design. Performance, ultrasonic, and carcass data were analyzed using the MIXED procedures of SAS (SAS Inst. Inc., Cary, NC). Additionally, the IML procedures of SAS were used to generate coefficients for unevenly spaced levels of CDS inclusion (e.g., 0, 10, 19, and 27%). These coefficients were used to generate linear and quadratic contrasts to describe the treatment effects of increasing CDS inclusion when a treatment effect was detected. A single degree of freedom contrast was also used to compare CNT to the 10% CDS diet because these diets contained similar dietary fat concentrations from different sources. Animal was defined as the experimental unit. Least squares means for treatment within feeding phase were generated and separated using the P-DIFF option of the LSMEANS statement. Differences were considered significant at $P \leq 0.05$ and trends were considered present at $0.05 < P \leq 0.10$.

Experiment 2

Animal and Diet Management. Five Angus–Simmental steers (BW = 335 ± 56 kg), previously fitted with rumen cannulae, were housed in metabolism stalls at the Beef Cattle and Sheep Field Research Laboratory at the University of Illinois, Urbana. Stalls (2.3 by 1.3 m) contained nonsiphoning water bowls and plastic feed bunks. The barn was environmentally controlled (average temperature = 20.0°C) with forced heating and cooling. In 6 adjacent stalls, there were 6 mobile open-circuit respiration chambers of the ventilated hood type for methane emissions measurement. Cattle were allotted (Patterson and Lucas, 1962) to 1 of 5 dietary treatments in a 5 × 5 Latin square design. Dietary treatments (Table 1) included 1) CNT, 2) 0% CDS, 3) 10% CDS, 4) 19% CDS, or 5) 27% CDS. Diets 2 through 5 included coproducts (corn gluten feed and soybean hulls) and were formulated to achieve fat concentrations of 3, 5, 7, and 9%, respectively. Feed was delivered once daily to allow ad libitum access to assigned diets. Refusals were collected each day and individual DMI was calculated.

Sampling and Analysis. Sampling periods were 21 d with 14-d acclimation periods for each treatment and 5 d for sampling. After initial acclimation to total mixed ration, steers underwent partial rumen evacuations (8 L). The rumen contents from evacuation were mixed and then redistributed to each animal to minimize initial differences in rumen microbial population. At the initiation of each subsequent acclimation period, rumens were totally evacuated and the contents from steers on each diet were transfused into the rumen of the steer assigned to that same diet for the following collection period.

On d 14 to 19, intake and fecal output were measured. Feed ingredient and refusal samples (50 g) were taken during this phase. Feed and refusal samples were collected on 5 consecutive days during the collection phase, composited, and freeze-dried (FreeZone[12]; Labconco) and then processed as described in Exp. 1. Refusals were collected and weighed and 10% of the refusals were retained for nutrient analysis. Feces were collected in canvas bags secured by a leather harness attached to the girth and under the neck. Feces were collected twice a day and weighed, and 5% of the feces were retained at each collection for later nutrient analysis. Retained samples were composited by animal within period, freeze-dried, ground, and analyzed for DM, fat, and NDF, as described in Exp. 1.

Rumen Fluid. On d 19, 150 mL of ruminal fluid was collected via rumen cannula at 0, 3, 6, 9, 12, and 18 h after feeding and filtered through 4 layers of cheesecloth, and pH was measured. Measurement of pH was accomplished within 2 min of collection using a FE20/FG2 pH meter (Mettler Toledo, Columbus, OH). To measure pH, the electrode (3 in 1 pH Electrode LE438 polyoxymethylene body gel-filled electrode with Ag/AgCl reference system and 1.2 m; BNC (Bayonet Neill–Concelman)/cinch connection) was submersed in unmodified rumen fluid.

At 0, 3, and 6 h, rumen fluid was sampled for quantification of VFA. Samples (50 to 75 mL) of rumen fluid were mixed with 10 mL of H_3PO_4 and deionized water was added to achieve a 2:1 dilution. The mixture was then placed in a refrigerator and remixed by shaking several times per day for 2 d. On d 3, samples

were removed from the refrigerator and 40 mL of rumen fluid was centrifuged at 20,000 ×g at 25°C for 20 min. Supernatant was filtered through a 0.45-µm filter. Filtered sample was then transferred in 1-mL aliquots to gas chromatography vials with 0.1 mL of 2-ethyl butyrate as an internal standard. Vials were then stored at –20°C until analyzed using a gas chromatograph (model 5890A; Hewlett-Packard, Palo Alto, CA) for VFA.

On d 20, steers were placed in 5 (1 steer per chamber) positively pressurized ventilated hood–type chambers called the Ruminant Emission Measurement System (**REMS**). A sixth chamber was left open as a blank to allow for correction of any error due to contamination from environmental methane. The REMS also features individual chamber thermal environmental control to maintain animal comfort and a fresh air supply for CO_2 control and measurement of incoming ventilation volumetric flow rate (Ramirez et al., 2014). Lastly, a gas sampling system managed gas collection via a solenoid multiplexer to infrared photoacoustic gas analyzer (INNOVA 1412; LumaSense Technologies, Inc., Santa Clara, CA), configured with CH4, CO2, N2O, NH3, and SF6 optical filters. More information regarding the REMS, including system description, operation, sampling integration time, and detection limits of the optical filters are reported by Sun (2013) and Ramirez (2014). The last 5 of 10 gas concentration and thermal environment measurements at each sampling location (6 chambers and barn [incoming]) were averaged every 86 min for approximately 24 h. Before and after each period the steers were in the REMS, a mass recovery test was performed to verify mass measurement was within the expected range for these chambers. Methane emissions were calculated using the following equation adapted from (Moody et al., 2008):

$$ER = \dot{V}_{in}\left[\left(\rho_{in}^{ma}/\rho_{ch}^{ma}\right)\left(C_{ch}/T_{ch}\right)-\left(C_{in}/T_{in}\right)\right]\times 10^{-6}\left[\left(M\times P_b\right)/R\right], \quad [1]$$

in which ER = emission rate, which is the generated gas mass flow (g/s); $\dot{V}_{in}$ = ventilation, which is the incoming moist air volume ric flow rate (m^3/s); ρ_{in}^{ma} = incoming moist air density (kg_{da}/m^3); ρ_{ch}^{ma} = chamber moist air density (kg of dry air [$\mathbf{kg_{da}}$]/m^3); C_{ch} = chamber methane concentration; C_{in} = incoming methane concentration µL/L); T_{in} = incoming dry-bulb temperature (K); T_{ch} = chamber dry-bulb temperature (K); M = molecular mass of methane (g/mol); P_b = local barometric pressure (98.639 kPa; ASHRAE, 2013); and R = universal ideal gas constant (8.314; $m^3{\cdot}Pa{\cdot}K^{-1}{\cdot}mol^{-1}$).

Methane ER were normalized to 24 h following a trapezoidal integration of the computed ER, resulting in a single CH_4 ER (g/h) for each steer within each period. Feed and water were provided inside the chamber for ad libitum intake.

Statistical Analysis. Experiment 2 was a 5 × 5 Latin square design with treatments assigned to animals according to Patterson and Lucas (1962). Data were analyzed using the MIXED procedures of SAS. The IML procedures of SAS were used to generate coefficients for unevenly spaced levels of CDS inclusion. These coefficients were used to generate linear and quadratic contrasts to determine effects of increasing CDS inclusion. The model included diet, time after feeding, and period. Additionally, a single degree of freedom contrast was used to compare CNT to the 10% CDS diet because these diets contained similar fat concentrations from differing sources. The REPEATED statement was used to analyze the effect of animal within treatment on rumen pH and VFA concentration. Least squares means were generated and separated using the PDIFF option of the LSMEANS statement. Differences were considered significant at $P \leq 0.05$ and trends were considered present at $0.05 < P \leq 0.10$.

RESULTS

Experiment 1

During the course of the trial, 1 steer died and 2 were removed from the study due to chronic health problems; therefore, data reflect the number of animals per treatment that were kept on feed from d 0 to 196. At the end of the growing phase (d 106), ADG increased ($P < 0.01$) by 0.45 kg for calves fed the starch-based CNT compared with those fed 10% CDS. As a result, calves fed CNT had increased ($P < 0.01$) BW, by 48 kg, compared with calves fed 10% CDS diets at d 106 (Table 2). Increasing inclusion of CDS resulted in increased (linear, $P = 0.02$) ADG. Also, BW increased (linear, $P = 0.03$) as CDS inclusion increased in coproduct diets. Calves consuming 10% CDS were lightest (349 kg) whereas cattle consuming 19% CDS were heaviest (378 kg) at d 106 among cattle fed coproducts. Dry matter intake was within a 0.86-kg range for all treatments during the growing phase; therefore, no differences ($P \geq 0.19$) were observed between CNT and 10% CDS or between diets with increasing CDS inclusion for DMI during the growing phase. Growing phase differences ($P \leq 0.02$) in ADG were sufficient to affect G:F. Steers fed CNT increased ($P < 0.01$) G:F by 0.04 units compared with 10% CDS. Efficiency of gain also increased ($P < 0.01$) with increasing CDS inclusion during the growing phase.

At the end of the finishing phase (d 196), steers fed CNT were heavier ($P < 0.01$) than steers fed 10% CDS; however, CDS inclusion, fed during the growing phase, did not affect ($P \geq 0.19$) final BW. Finishing

Table 2. Growth performance of early-weaned calves fed a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS) in Exp. 1

	Diet						Contrast		
		CDS inclusion					CNT vs.	CDS inclusion[1]	
Item	CNT	0%	10%	19%	27%	SEM	10%	Linear	Quadratic
No.	7	8	8	7	7				
Initial BW, kg	190	183	184	184	183	26.05	0.66	0.96	0.94
d 106[2]									
BW, kg	397	353	349	378	370	17.79	<0.01	0.03	0.95
ADG, kg	2.00	1.59	1.55	1.82	1.75	0.17	<0.01	0.02	0.96
DMI, kg	9.13	8.27	8.61	8.81	8.27	0.75	0.27	0.83	0.19
G:F	0.22	0.19	0.18	0.21	0.21	0.01	<0.01	<0.01	0.08
d 196[3]									
BW, kg	548	505	508	518	520	23.21	<0.01	0.19	0.98
ADG, kg	1.69	1.68	1.77	1.56	1.67	0.23	0.56	0.60	0.97
DMI, kg	12.76	11.79	12.25	11.95	12.01	0.96	0.40	0.82	0.60
G:F	0.13	0.14	0.15	0.13	0.14	0.01	0.16	0.43	0.84
Overall[4]									
ADG, kg	1.85	1.63	1.65	1.70	1.71	0.12	0.01	0.19	0.96
DMI, kg	10.96	9.83	10.24	10.55	10.38	0.38	0.20	0.25	0.50
G:F	0.17	0.17	0.16	0.17	0.17	0.01	0.16	0.30	0.40

[1]Linear and quadratic effects of 0, 10, 19, and 27% CDS inclusion.

[2]Means generated at the end of growing phase after feeding of experimental diets.

[3]Means generated at the end of the finishing phase after feeding a common diet.

[4]Means calculated for growing and finishing period (from weaning until slaughter).

phase ADG, DMI and G:F were not different ($P \geq 0.16$) between CNT and 10% CDS nor were they affected ($P \geq 0.43$) by increasing CDS inclusion. However, growing phase differences in ADG were sufficient to affect overall ADG from weaning to slaughter. Steers fed CNT had an increased ($P < 0.01$) ADG, by 0.20 kg, compared with steers fed 10% CDS between weaning and slaughter. Increasing dietary inclusion of CDS had no effect ($P \geq 0.19$) on overall ADG. Overall DMI and G:F were not different ($P \geq 0.16$) in any of the contrasts.

Ultrasound indicated BF increased ($P = 0.02$) by 2.31 mm in steers fed CNT compared with 10% CDS (Table 3) at the end of growing phase; however, BF was not different ($P = 0.12$) between CNT and 10% CDS nor was it affected ($P \geq 0.12$) by increasing CDS inclusion at the end of the finishing phase. At the end of the growing phase, there was no difference ($P \geq 0.21$) in MS between steers fed CNT and steers fed 10% CDS. Additionally, there was no difference ($P \geq 0.35$) in MS between steers fed increasing CDS inclusions at the end of the growing phase. Ultrasound measurements collected the day before harvest revealed no difference ($P \geq 0.12$) in BF due to CDS. Steers fed CNT tended ($P = 0.07$) to have higher ultrasound MS than cattle fed 10% CDS at d 196. Marbling scores also tended (linear, $P = 0.08$) to increase as CDS inclusion increased.

Table 3. Ultrasound data for early-weaned calves fed a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS) in Exp. 1

	Diet						Contrast		
		CDS inclusion					CNT vs.	CDS inclusion[1]	
Item	CNT	0%	10%	19%	27%	SEM	10%	Linear	Quadratic
No.	7	8	8	7	7				
d 106[2]									
Back fat, mm	8.01	5.95	5.70	6.07	5.01	0.68	0.02	0.37	0.51
Marbling score[3]	377	321	337	377	348	23.00	0.21	0.35	0.52
d 196[4]									
Back fat, mm	13.42	12.94	10.76	11.55	10.79	1.2	0.12	0.21	0.51
Marbling score	594	484	509	584	543	33.0	0.07	0.08	0.39

[1]Linear and quadratic effects of 0, 10, 19, and 27% CDS inclusion.

[2]Means generated at the end of growing phase after feeding of experimental diets.

[3]100 = practically devoid, 200 = traces, 300 = slight, 400 = small, 500 = modest, 600 = moderate, 700 = slightly abundant, 800 = moderately abundant.

[4]Means generated at the end of the finishing phase after feeding a common diet.

Table 4. Carcass data for early-weaned calves fed a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS) in Exp. 1

	Diet						Contrast		
		CDS inclusion					CNT vs.	CDS inclusion[1]	
Item	CNT	0%	10%	19%	27%	SEM	10%	Linear	Quadratic
Carcasses	7	8	8	7	7				
HCW, kg	340	329	324	329	306	14.18	0.42	0.32	0.52
LM area, cm^2	78.74	69.28	76.90	78.66	74.08	3.29	0.69	0.23	0.07
Marbling score[2]	474	410	433	479	424	34.04	0.38	0.60	0.33
Back fat, cm	0.95	1.06	0.85	1.26	1.13	1.26	0.69	0.43	0.70
KPH, %	2.0	2.3	2.2	2.1	2.1	0.10	0.14	0.15	0.69
Yield grade	3.26	3.28	3.24	2.98	3.12	0.21	0.97	0.41	0.72
Select, %	29.0	50.0	29.0	29.0	29.0	0.18	0.97	0.44	0.56
$Choice^-$ or better, %	71.0	50.0	71.0	71.0	71.0	0.18	0.97	0.44	0.56
$Choice^0$ or better, %	43.0	13.0	14.0	43.0	14.0	0.15	0.20	0.77	0.37
Prime, %	0.0	0.0	0.0	14.0	0.0	0.06	0.99	0.57	0.28

[1]Linear and quadratic effects of 0, 10, 19, and 27% CDS inclusion.

[2]100 = practically devoid, 200 = traces, 300 = slight, 400 = small, 500 = modest, 600 = moderate, 700 = slightly abundant, 800 = moderately abundant.

Longissimus muscle area was not different (P = 0.69) in steers fed CNT compared with those fed 10% CDS; however, steers fed either 10 or 19% CDS tended (quadratic, P = 0.07) to have larger LM areas than steers fed 0 or 27% CDS (Table 4). Other carcass traits, including HCW, BF, marbling, KPH, yield grade, and USDA quality grade, were not different ($P \geq 0.14$) between CDS and CNT nor were they affected ($P \geq 0.15$) by increasing CDS inclusion.

Experiment 2

There was no effect ($P \geq 0.24$) of treatment on DMI; however, DM digestibility in calves fed CNT was increased (P = 0.01) by 5.84 percentage units compared with calves fed diets with 10% CDS inclusion (Table 5). Also, DM digestibility in calves fed coproduct diets increased (linear, P = 0.02) as dietary CDS inclusion increased. Similarly, fat digestibility increased (linear, $P < 0.01$) as dietary inclusion of CDS increased. Steers fed CNT tended to have decreased (P = 0.07) fat digestibility compared with steers fed 10% CDS. Digestibility of NDF was not different ($P \geq 0.17$) between CNT and 10% CDS inclusion or affected ($P \geq 0.39$) by increasing CDS inclusion.

There was no difference (P = 0.87) in ruminal pH between CNT and 10% CDS inclusion and they were not affected ($P \geq 0.84$) by increasing CDS inclusion. Also, no treatment × time interaction (P = 0.84) on ruminal pH was detected; however, time after feeding decreased ($P < 0.01$) pH until h 12 (Fig. 1). Concentrations of acetate, propionate, and total VFA were not different ($P \geq 0.23$) between CNT and 10% CDS inclusion; they were not affected ($P \geq 0.13$) by CDS inclusion, and no treatment × time interactions ($P \geq 0.47$) were observed (Table 6). There was an effect of time ($P < 0.01$) on concentrations of acetate and propionate; they increased between 0 and 3 h after feeding but remained similar ($P \geq 0.73$) between 3 and 6 h. Acetate:propionate ratio decreased ($P < 0.01$) between 0 and 3 h after feeding but did not differ (P = 0.71) from 3 to 6 h after feeding. Finally, daily meth-

Table 5. Digestibility of DM, NDF, ADF, and ether extract in steers fed a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS) in Exp. 2

	Diet						Contrast		
		CDS inclusion					CNT vs.	CDS inclusion[1]	
Item	CNT	0%	10%	19%	27%	SEM	10% CDS	Linear	Quadratic
No.	5	5	5	5	5				
DMI, kg/d	10.04	11.39	11.53	10.97	10.62	0.86	0.24	0.48	0.74
Digestibility, %									
DM	77.58	67.91	71.74	73.84	72.45	1.41	0.01	0.02	0.11
NDF	69.63	63.73	65.45	65.94	63.97	2.05	0.17	0.86	0.39
ADF	71.57	65.90	67.65	66.91	69.38	3.07	0.38	0.49	0.91
Fat	83.91	76.01	87.35	87.97	87.04	1.25	0.07	<0.01	0.02

[1]Linear and quadratic effects of 0, 10, 19, and 27% CDS inclusion.

Table 6. Ruminal VFA concentrations in steers fed a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS) in Exp. 2

	Diet									Contrast		
		CDS inclusion							Diet ×	CNT vs.	CDS inclusion[1]	
Item	CNT	0%	10%	19%	27%	SEM	Diet	Time	time	10%	Linear	Quadratic
Steers	5	5	5	5	5							
VFA												
Acetate, mM						4.40	0.55	<0.01	0.47	0.72	0.13	0.83
0 h[2]	46.29	59.03	46.33	45.48	45.66							
3 h	62.21	64.57	61.52	61.18	55.14							
6 h	64.35	62.31	59.37	64.93	57.34							
Propionate, mM						4.52	0.70	<0.01	0.66	0.60	0.22	0.96
0 h	25.37	21.18	18.31	17.92	16.65							
3 h	40.95	33.69	36.31	33.94	28.25							
6 h	41.26	30.56	33.97	36.38	31.20							
Total VFA, mM						9.46	0.70	<0.01	0.66	0.60	0.22	0.96
0 h	86.81	99.87	79.39	76.17	78.17							
3 h	124.03	124.94	123.01	117.73	105.87							
6 h	125.62	117.93	115.92	122.79	112.67							
A:P[3] ratio						0.27	0.55	<0.01	0.51	0.23	0.80	0.83
0 h	2.00	2.92	2.87	2.92	2.85							
3 h	1.64	2.01	1.82	1.88	1.95							
6 h	1.68	2.08	1.90	1.97	1.87							

[1]Linear and quadratic effects of 0, 10, 19, and 27% CDS inclusion.

[2]Hours after feed delivery.

[3]A:P = acetate:propionate.

ane emissions from steers fed CNT were not different ($P = 0.37$) when compared with steers fed 10% CDS, and increasing CDS inclusion in the diet had no effect ($P \geq 0.69$) on ruminal methane emissions (Fig. 2).

DISCUSSION

Experiment 1

At the end of the growing phase, steers fed CNT were more efficient, faster growing, and heavier than those fed 10% CDS. This response was likely the result of increased energy in the CNT. Both CNT and 10% CDS were formulated to contain similar fat concentrations, but CNT analyzed with 0.9% units more fat than did the 10% CDS diet (5.3 and 4.4%, respectively). The CNT also contained corn, whereas the 10% CDS diet contained predominantly corn gluten feed and soy bean hulls. The contrast of CNT to the 10% CDS coproduct diet was made to illustrate the effect of corn in a standard early-weaned calf diet compared with a coproduct diet containing CDS formulated to have similar concentrations of dietary fat; however, slightly higher fat concentrations as well as starch found in CNT likely had an impact on performance. Increased ADG in cattle fed corn compared with calves fed coproducts has been observed (Neville and McCormick, 1981; Schoonmaker et al., 2003; Arthington et al., 2005). These studies differ from the current study in that they used forage-based diets compared with corn-based diets. Meteer et al. (2012) observed no differences in ADG in early-weaned calves fed either starch- or coproduct-based growing diets, but in that study, calves consuming coproduct diets consumed 0.88 kg/d more than calves fed starch-based diets. Segers et al. (2014) noted increased ADG in cattle fed corn during the growing phase but increased DMI in cattle fed coproducts when comparing coproduct-based diets to corn-based diets. Segers et al. (2014) also observed no difference in final BW. These data indicate that because corn-based diets are more energy dense, they tend to produce higher gains and limit DMI compared with coproducts such as distillers' grains or corn gluten feed; however, in the current study, DMI was not different between CNT and 10% CDS. There was a numerical decline in DMI as CDS inclusion increased.

Replacing corn with some coproducts, such as corn gluten feed and soybean hulls, has been shown to alleviate intake-limiting factors associated with corn-based diets such as negative associative effects as well as subacute and clinical acidosis (Green et al., 1987; Krehbiel et al., 1995). In the current study, decreased ADG observed in calves fed 10% CDS compared with CNT during the growing phase is likely a function of decreased energy intake due to similar DMI observed in calves from all treatments. Numerically decreasing DMI in calves fed

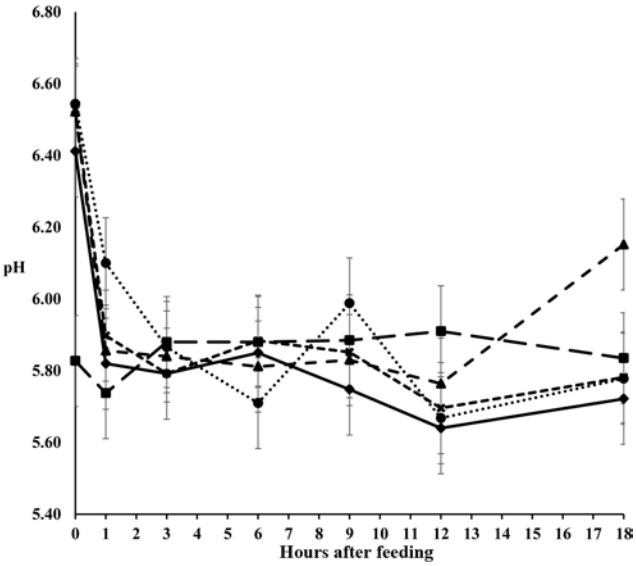

Figure 1. Ruminal pH (SEM = 0.15) from steers fed diets including a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS). Diets fed to steers contained either CNT (♦) or 0 (■), 10 (▲), 19 (×), or 27% (●) CDS. Ruminal pH decreased ($P < 0.01$) over time. No effects of treatment or treatment × time were detected ($P \geq 0.84$).

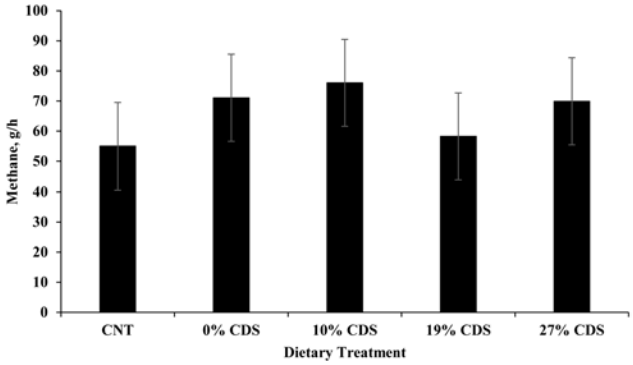

Figure 2. Ruminal methane emissions (SEM = 11.99) from steers fed diets including a corn-based growing diet (CNT) or coproduct blends with increasing concentrations of dietary fat from condensed corn distillers' solubles (CDS). Diets fed to steers contained either CNT or 0, 10, 19, or 27% CDS. There was no effect ($P \geq 0.37$) of diet on ruminal methane emission.

CDS may be the result of increased dietary sulfur concentrations in diets containing CDS. Felix et al. (2012b) conducted a dose titration experiment using dried distillers' grains with solubles (**DDGS**) at increasing inclusion rates (0, 20, 40, and 60%). The authors observed a linear decrease in DMI in congruence with increased DDGS inclusion (Felix et al., 2012b). This effect has been attributed, in part, to increased sulfur concentration in the rumen as a result of increasing the inclusion level of DDGS (Felix et al., 2012b; Ham et al., 1994; Klopfenstein et al., 2008). Sulfuric acid is used to modulate pH during starch hydrolysis and to clean the plants after fermentation (Klopfenstein et al., 2008). At least a portion of this sulfuric acid is transferred to distillers' coproducts thereby adding to dietary sulfur concentrations and decreasing pH of the diet (Felix and Loerch, 2011). Chemical analysis of diets used in the current study revealed increasing sulfur concentrations of 0.34, 0.41, 0.47, and 0.53% with increasing CDS inclusion compared with 0.23% in the CNT; therefore, it is possible that increased dietary sulfur intake was partially responsible for lower than expected intakes in diets containing CDS. Although ADG, DMI, and G:F were not different during the finishing phase, ADG differences in the growing phase were sufficient to increase overall ADG in CNT compared with those fed 10% CDS. Similarly, the linear increase in ADG by calves in the growing phase was sufficient to generate a linear increase in ADG as the inclusion of CDS increased in coproduct diets.

Carcass weights from steers fed CNT were similar to those from steers fed coproducts with 10% CDS inclusion and were unaffected by increasing CDS inclusion. Previous research (Meteer et al., 2012; Segers et al., 2014) has demonstrated that cattle fed high-fat coproduct blends can achieve performance and HCW similar to cattle fed corn during the growing phase. As noted earlier, the BW and ADG advantage of CNT over coproducts with 10% CDS inclusion was likely a function of increased dietary energy of corn and increased fat concentration. Calves fed CNT received a diet that contained 1.15 Mcal/kg of NEg whereas calves fed 10% CDS inclusion consumed a diet that contained 1.02 Mcal/kg of NEg, resulting in heavier animals at slaughter. It is unclear why increased BW at d 196 did not translate into larger HCW in CNT-fed steers compared with those fed 10% CDS. The quadratic trend observed for LM area is not well explained in the literature and requires further research to offer a viable explanation without speculation.

Final carcass ultrasound revealed a linear trend for increased MS as CDS inclusion increased; this trend was not observed in the carcass data, which revealed no difference in MS among treatments. The authors hypothesized that increased CDS inclusion and the subsequent increase in dietary fat would decrease fiber digestibility and shift ruminal fermentation to favor greater propionate production. The authors expected the aforementioned increase in ruminal propionate concentration in calves to correspond with increased MS in the carcass. The inability to detect marbling differences in the carcass may be a function of low animal numbers making it difficult to detect differences for this trait. Corn-based diets have been shown to improve intramuscular fat deposition (Schoonmaker et al., 2003, 2004b) and subsequent MS (Myers et al., 1999) compared with fiber-based diets when used in accelerated finishing systems that use early weaning. Therefore, it was believed that starch was a necessary dietary com-

ponent to improve marbling and subsequent carcass quality in early-weaned calves. More recent research indicates there may be an alternative mechanism for using early calf nutrition to maintain high quality beef using coproducts instead of corn during the growing phase. Meteer et al. (2012) found no difference in MS when comparing corn to corn bran (9% fat) as energy sources fed to early-weaned calves. Also, Segers et al. (2014) illustrated that coproduct diets containing 5% fat from coproducts fed to early-weaned calves produce carcasses with MS similar to those from calves fed corn in the first 112 d after weaning.

Experiment 2

Dry matter intake was not different among treatments for fistulated steers. There was a numerical decrease in DMI as CDS inclusion increased resulting in 0.77 kg/d spread from 0 to 27% CDS. This trend failed to gain significance likely because the steers in Exp. 2 had fewer days on feed than calves in Exp. 1 and previously had been exposed to diets with increased concentrations of sulfur allowing the rumen greater acclimation time to increased sulfur concentrations and minimizing the effects of the dose titration on DMI. However, Gilbery et al. (2006) observed a linear increase in DMI and digestibility when CDS was fed at 0, 5, 10, or 15% DM inclusion with switchgrass hay (*Panicum virgatum* L.). This increase was attributed to increased degradable intake protein in CDS, providing sufficient nitrogen for fibrolytic microbial populations to flourish in the rumen (Gilbery et al., 2006). In the current experiment, digestibility of DM was increased in CNT-fed steers compared with steers fed coproducts with 10% CDS inclusion, but DM digestibility increased as CDS inclusion increased in coproduct diets. Similarly, fat digestibility increased as CDS inclusion increased. These data were not unexpected as corn is a readily fermentable substrate, and CDS has already been shown to increase the digestibility of low quality hay (Gilbery et al., 2006). However, there was no effect of CDS inclusion on NDF or ADF digestibility. Historically, when diets contained high concentrations of fat (greater than 5% of total DMI), fiber digestibility and DMI were impeded (Byers and Schelling, 1993; Coppock and Wilks, 1991). This occurs because the hydrophobic nature of the lipids forces the fat to surround and encapsulate fiber thereby limiting microbial attachment. Also, modification of the microorganism population, surface-active effects on microbial membranes, and lowered cation availability through the rumen can occur with little to no effect on microflora populations (Jenkins, 1993). Currently, it is thought that perhaps fat from corn coproducts such as distillers' grains with solubles or CDS behaves differently in the rumen than other unsaturated fat supplements such as corn oil. Klopfenstein et al. (2008) outlined an experiment in which DDGS was fed to feedlot cattle in comparison to corn oil. Cattle fed DDGS increased G:F by 8% whereas cattle fed corn oil decreased G:F by 10% compared with cattle fed dry-rolled corn. Additionally, 81% of the fat fed to DDGS cattle was digested as opposed to 70% by cattle fed corn oil (Klopfenstein et al., 2008).

In the current study, we had also hypothesized that increasing dietary fat from CDS would increase ruminal propionate concentration, thereby increasing the potential for increased intramuscular fat deposition and greater MS in feedlot cattle. However, there was no effect of treatment on ruminal pH or VFA concentration. This may also be due to the altered fermentation of fat from coproducts in comparison to other unsaturated fats. In the case of SFA, ruminal hydrolysis occurs with 40 to 50% efficiency, whereas PUFA are hydrolyzed with, at most, 35% efficiency (Thomas et al., 1997). After hydrolysis, the resulting glycerol is fermented to produce propionate (Byers and Schelling, 1993). Smith and Crouse (1984) hypothesized that increased ruminal propionate production, in cattle fed high starch diets, caused increased blood glucose concentration providing more carbon substrate for intramuscular lipogenesis. Felix et al. (2012a) reported decreased concentrations of propionate at 0 h after feeding in cattle fed 60% DDGS diets compared with those fed 25% DDGS diets; however, by 3 and 6 h after feeding, ruminal propionate concentrations were greater in cattle fed 60% DDGS diets. Vander Pol et al. (2009) reported decreased acetate and increased propionate were found in diets containing wet distillers' grains with solubles (**WDGS**) compared with corn bran. They hypothesized that it was possible that the level of solubles inclusion in WDGS or DDGS could affect digestion and VFA concentration (Vander Pol et al., 2009).

Ruminal methane production was not affected by treatment in the current study. This finding was unexpected. The authors hypothesized that increasing dietary fat from CDS would decrease ruminal methane emissions. Lipids have been shown to have a negative impact on methane production through several processes, including enhancing propionate production, biohydrogenation, and protozoal inhibition (Johnson and Johnson, 1995). Czerkawski et al. (1966) infused the rumen of sheep with oleic, linoleic, or linolenic acid. All animals displayed decreased ($P < 0.01$) methane production by at least 13.8% with infusion of PUFA (Czerkawski et al., 1966). The authors hypothesized that the reduction in methane was due to biohydrogenation of the double bonds by rumen microorganisms and that the PUFA provided an alternative hydrogen sink to CO_2 (Czerkawski et al., 1966). Other studies have re-

vealed similar results with diets containing soybean oil and tallow compared with isocaloric controls (Swift et al., 1948; Haaland, 1978; Van der Honing et al., 1981). These studies attributed decreased methane production to encapsulation of feed particles by lipid thereby limiting the opportunity for microbial attachment and decreasing the amount of fermentable substrate.

In conclusion, steers fed a corn-based CNT during the growing phase tended to be heavier at slaughter and produced carcasses similar to those fed coproducts with 10% CDS inclusion. Increasing inclusion of CDS improved growing phase ADG and did not impede performance in steers fed CDS. Dietary fat inclusion from CDS increased predicted MS via ultrasound but had no significant impact on marbling at slaughter. There were no effects of including CDS up to 27% of the diet on NDF or ADF digestibility, VFA production, pH, or ruminal methane production. These data indicate that CDS are a viable energy source for use in beef cattle diets that may be included in rations at rates up to 27% DM with no detrimental effects on performance, carcass characteristics, ruminal fermentation, or nutrient digestibility.

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