Evaluation of corn germ from ethanol production as an alternative fat source in dairy cow diets¹

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ABSTRACT

Sixteen multiparous cows (12 Holstein and 4 Brown Swiss, 132 ± 20 d in milk) were used in a replicated 4 × 4 Latin square design with 4-wk periods to determine the effects of feeding corn germ on dairy cow performance. Diets were formulated with increasing concentrations of corn germ (Dakota Germ, Poet Nutrition, Sioux Falls, SD) at 0, 7, 14, and 21% of the diet dry matter (DM). All diets had a 55:45 forage to concentrate ratio, where forage was 55% corn silage and 45% alfalfa hay. Dietary fat increased from 4.8% in the control diet to 8.2% at the greatest inclusion level of corn germ. The addition of corn germ resulted in a quadratic response in DM intake with numerically greater intake at 14% of diet DM. Feeding corn germ at 7 and 14% of diet DM increased milk yield and energy-corrected milk as well as fat percentage and yield. Milk protein yield tended to decrease as the concentration of corn germ increased in the diet. Dietary treatments had no effect on feed efficiency, which averaged 1.40 kg of energy-corrected milk/kg of DMI. Increasing the dietary concentration of corn germ resulted in a linear increase in milk fat concentrations of monounsaturated and polyunsaturated fatty acids at the expense of saturated fatty acids. Milk fat concentration and yield of *cis*-9, *trans*-11 and *trans*-10, *cis*-12 conjugated linoleic acid were increased with increased dietary concentrations of corn germ. Although milk fat concentrations of both total *trans*-18:1 and *cis*-18:1 fatty acids increased linearly, a marked numeric increase in the concentration of *trans*-10 C18:1 was observed in milk from cows fed the 21% corn germ diet. A similar response was observed in plasma concentration of *trans*-10 C18:1. Feeding increasing concentrations of corn germ had no effect on plasma concentrations of glucose, triglyceride, or β-hydroxybutyrate; however, the concentration of

nonesterified fatty acids increased linearly, with plasma cholesterol concentration demonstrating a similar trend. Germ removed from corn grain before ethanol production provides an alternative source of fat for energy in lactating dairy cows when fed at 7 and 14% of diet DM. Our results suggest that fat from corn germ may be relatively protected with no adverse effect on DM intake, milk production, and milk composition when fed up to 14% of diet DM.

Key words: corn germ, fat, fatty acid, cow

INTRODUCTION

Feeding fats to dairy cows is a common practice to increase the energy density of the diet. Vegetable oil, oilseeds, and soaps of long-chain fatty acids (**LCFA**) are common fat sources used in dairy cow diets (NRC, 2001). With the rapid expansion of the ethanol industry, alternative fat sources are becoming available in the form of corn coproducts such as corn germ (**CG**) and dry and wet distillers grains with solubles. Corn coproducts are major sources of linoleic acid. Feeding fat supplements rich in linoleic and linolenic acids has been shown to increase concentrations of polyunsaturated fatty acids (**PUFA**) in milk, especially the concentration of conjugated linoleic acid (**CLA**) and its precursor vaccenic acid (**VA**; Dhiman et al., 2000; Chouinard et al., 2001).

Corn coproducts are attractive to dairy and beef cattle producers because of their high energy, protein, and fiber contents, and low starch content compared with corn. Corn germ is obtained during the corn wet milling or dry grind process (Moreau et al., 2005). Corn germ produced during the wet milling process contains about 40 to 50% fat. The fat content of CG produced through the dry grinding process, however, is about 20 to 25% (Moreau et al., 2005). Regardless of source, CG contains a greater concentration of fat compared with the original grain source.

Feeding large amounts of dietary fat to ruminants can negatively affect DMI, milk production, and milk fat concentration (Griinari et al., 1998; NRC, 2001). Therefore, milk fat depression is a major concern when

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Table 1. Ingredient composition of diets containing increasing concentration of corn germ (CG)

Ingredient, % of DM	Dietary treatment (% CG)			
	0	7	14	21
Alfalfa hay	25.0	25.0	25.0	25.0
Corn silage	30.0	30.0	30.0	30.0
Ground corn	28.5	22.9	17.2	11.6
Soybean meal, 44%, solvent-extracted	8.5	7.2	5.8	4.5
Soybeans, extruded	5.0	5.0	5.0	5.0
Fish meal, menhaden	1.0	1.0	1.0	1.0
Corn germ	0.0	7.0	14.0	21.0
Vitamin/mineral premix ¹	0.25	0.25	0.25	0.25
Limestone	0.80	0.80	0.80	0.80
Magnesium oxide	0.10	0.10	0.10	0.10
Salt	0.45	0.45	0.45	0.45
Sodium bicarbonate	0.20	0.20	0.20	0.20
Zinpro 4-Plex ²	0.20	0.20	0.20	0.20

¹Dairy Micro Premix (Land O'Lakes Inc., St. Paul, MN); contained 10% Mg, 4,783 mg/kg Fe, 4,857 mg/kg Cu, 122 mg/kg Co, 17,793 mg/kg Mn, 26,556 mg/kg Zn, 408 mg/kg I, 144 mg/kg Se, 545,000 IU/kg vitamin A, 109,000 IU/kg vitamin D, and 2,181 IU/kg vitamin E.

²Zinpro Corp., Eden Prairie, MN.

feeding large amounts of high-fat corn coproducts to dairy cows. Inclusion of 4% corn oil in a low forage diet resulted in a 30 and 35% decrease in milk fat percentage and yield, respectively (Griinari et al., 1998). Milk fat percentage has been reported to decrease linearly when feeding increasing concentrations of dried distillers grains with solubles (Leonardi et al., 2005). Several studies have been conducted to evaluate distillers grains coproducts as potential feeds for cattle; however, no research data have been reported either on the use of CG as an alternative fat source, or on the upper limit for inclusion in dairy cattle diets. The objective of this study was to evaluate CG as a potential source of fat for dairy cows and its effect on DMI, milk production and composition, and milk CLA concentration as affected by feeding increasing concentrations of CG.

MATERIALS AND METHODS

Animals and Diets

Sixteen multiparous cows (12 Holstein and 4 Brown Swiss, 132 ± 20 DIM) were used in a multiple 4×4 Latin square design with 4-wk experimental periods. The first 2 wk were used for diet adaptation and the last 2 wk for sampling and data collection. Cows were blocked according to DIM, and dietary treatments were randomly assigned to cows within each block. Cows' BW and BCS were recorded at the beginning of the first period and during the last 3 d of each period. Diets were formulated with increasing concentrations of CG (Dakota Germ, Poet Nutrition, Sioux Falls, SD) at 0, 7, 14, and 21% of the diet DM (Table 1). All diets had a 55:45 forage to concentrate ratio, where forage con-

sisted of 55% corn silage and 45% alfalfa hay. Dietary fat increased from 4.8% in the control diet to 8.2% at the greatest inclusion rate of CG (Table 2). Dietary treatments were formulated to meet or exceed NRC nutrient requirements (NRC, 2001) for cows producing 45 kg of milk per day at 28.5 kg of daily DMI. Cows were housed in a free-stall barn and individually fed once daily (0800 h) for ad libitum intake using Calan Broadbent feeder doors (American Calan Inc., Northwood, NH). Amounts fed and refused were recorded daily and adjusted to allow for 5 to 10% refusals. Cows were milked 3 times daily at 0600, 1400, and 2100 h, and milk yield was recorded at each milking.

Sampling and Chemical Analysis

Samples of alfalfa hay, corn silage, concentrates, and complete diet were collected weekly. Corn silage and diet samples were stored at -20°C until analysis. Alfalfa hay and concentrate samples were stored at room temperature. Feed samples were made into composites by period and dried at 55°C in a forced-air oven (style V-23, Despatch Oven Co., Minneapolis, MN) for 48 h and then ground through a 2-mm screen using a Wiley mill (model 3; Arthur H. Thomas Co., Philadelphia, PA). Samples were reground through a 1-mm screen (Brinkman ultracentrifuge mill, Brinkman Instruments Co., Westbury, NY). Subsamples of feed composites were dried at 105°C for 4 h to determine DM. Composites were analyzed for CP, ether extract (**EE**), and ash according to AOAC methods (AOAC, 2002). Composites were analyzed for NDF with heat-stable α -amylase and sodium sulfite (Van Soest et al., 1991), ADF (Robertson and Van Soest, 1981), and acid deter-

Table 2. Nutrient composition of diets (% of DM unless otherwise noted) containing increasing concentrations of corn germ (CG; $n = 4$)¹

Item	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ²		
	0	7	14	21		L	Q	C
DM, %	55.5	55.6	56.3	57.0	0.34	0.002	0.07	0.56
CP, % of DM	17.4	17.4	17.3	17.3	0.09	0.31	0.88	0.53
NDF, % of DM	28.3	28.8	29.8	30.7	0.29	<0.001	0.55	0.82
Forage NDF, % of DM	23.5	23.5	23.5	23.5				
ADF, % of DM	17.1	16.9	17.0	17.0	0.16	0.99	0.24	0.31
NFC, ³ % of DM	42.6	41.3	39.3	37.3	0.52	<0.001	0.46	0.74
Starch, % of DM	24.0	23.3	21.6	19.3	0.70	<0.001	0.28	0.91
Ether extract, % of DM	4.8	5.9	7.1	8.2	0.05	<0.001	0.91	0.10
Ca, % of DM	0.73	0.74	0.72	0.70	0.03	0.42	0.35	0.93
P, % of DM	0.32	0.40	0.44	0.52	0.01	<0.001	0.90	0.96
Mg, % of DM	0.26	0.29	0.31	0.33	0.01	<0.001	0.32	0.19
NE _L , ⁴ Mcal/kg	1.56	1.60	1.64	1.68				

¹Number of samples used for each analysis; each sample was run in duplicate.

²Contrasts: L = linear, Q = quadratic, and C = cubic.

³NFC = 100 - (% NDF + % CP + % ether extract + % ash).

⁴Calculated using NRC (2001).

gent lignin (Lowry et al., 1994) sequentially using an Ankom²⁰⁰ fiber analyzer (Ankom Technology, Fairport, NY). Starch content was determined as described by Bach Knudsen (1997).

Feed fatty acids were prepared as butyl esters according to the Sukhija and Palmquist (1988) procedure with some modifications. Briefly, 100 to 150 mg of sample was placed into 16 × 100-mm Pyrex extraction tubes with Teflon-lined screw caps, followed by the addition of 750 µL of butanol and 25 µL of internal standard (12-nonadecenoic acid, Nu-Chek Prep Inc., Elysian, MN) and vortexed for 20 s. Samples were vortexed at low speed while slowly adding 150 µL of acetyl chloride; then, 750 µL of butanol was used to wash the wall of the extraction tube, the tube was gassed with N₂, capped tightly, and heated on a dry heating block at 100°C for 90 min. After samples cooled to room temperature, 8 mL of 6% K₂CO₃ was added and the samples were vortexed for 30 s. One milliliter of hexane was added and samples were vortexed for another 30 s. Samples were then centrifuged for 25 min at 2,800 × *g*, and the bottom layer was aspirated and discarded. The remaining hexane layer containing butyl esters was washed 4 times with distilled deionized water and centrifuged for 25 min at 2,800 × *g*. The upper layer, containing hexane and butyl esters of fatty acids, was removed and placed in injection vials for GC analysis.

Milk samples from each of the 3 daily milkings were collected for 3 consecutive days at the end of each period. Samples were mixed by gentle inversion and composited in volumes corresponding to the respective milking for each cow on the sampling day, and 2 milk aliquots were obtained for each day. One aliquot was sent to Heart of America DHI laboratory

(Manhattan, KS) for compositional analysis, where fat, true protein, and lactose were determined using mid-infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer, Bentley Instruments, Chaska, MN; method 972.16; AOAC, 2002). Concentrations of MUN were determined using chemical methodology based on a modified Berthelot reaction (ChemSpec 150 Analyzer, Bentley Instruments), and somatic cells were counted using a flow cytometer laser (Somacount 500; Bentley Instruments; method 975.16; AOAC, 2002). The second aliquot of milk was stored at -20°C until analysis for fatty acids. Milk fatty acids were prepared as butyl esters with a minor modification of the Sukhija and Palmquist (1988) procedure. Briefly, milk samples (10 mL) were centrifuged at 2,800 × *g* for 30 min at room temperature. The top fat layer was removed, transferred into microcentrifuge tubes, and centrifuged at 2,800 × *g* for 30 min at room temperature. The fat (10 to 20 mg) was then placed into 13 × 100-mm Pyrex extraction tubes with Teflon-lined screw caps, followed by the addition of 750 µL of butanol and 25 µL of internal standard (12-tridecenoic acid, Nu-Chek Prep Inc.), and vortexed for 20 s. Samples were vortexed at low speed while slowly adding 75 µL of acetyl chloride; then, tubes were gassed with N₂, capped tightly, and heated on a dry heating block at 100°C for 90 min. After samples cooled to room temperature, 5 mL of 6% K₂CO₃ was added and the samples vortexed for 30 s. Subsequently, 1 mL of hexane was added and samples were again vortexed for 30 s. Samples were then centrifuged for 25 min at 2,700 × *g*, and the bottom layer was aspirated and discarded. The remaining hexane layer containing butyl esters was washed 4 times with distilled deionized water and centrifuged for 25 min at 2,700 × *g*. The up-

per layer containing hexane and fatty acid esters were removed and placed in injection vials for GC analysis.

Samples of blood from the coccygeal vein and the subcutaneous mammary vein were collected into evacuated tubes (Becton Dickinson and Co., Franklin Lakes, NJ) containing K-EDTA approximately 3 to 4 h after feeding on 3 consecutive days at the end of each period. Samples were immediately placed on ice and transported to the laboratory where they were centrifuged ($2,700 \times g$). Plasma was collected and stored at -20°C until analysis. Coccygeal plasma samples were thawed and analyzed for glucose using glucose oxidase (Glucose kit, cat. no. G7521, Pointe Scientific, Canton, MI) according to Trinder (1969). The concentration of BHBA in plasma was determined (BHBA kit, cat. no. H7587-58, Pointe Scientific) following the methods of Williamson et al. (1962). The NEFA concentration was determined following modifications of the procedure of Johnson and Peters (1993) (NEFA-C kit, Wako Chemicals, Richmond, VA). Plasma triglyceride concentration was determined (TG kit, cat. no. T7532, Pointe Scientific) according to the procedure of Fossati and Lorenzo (1982). Total cholesterol was determined (Cholesterol kit, cat. no. C7510, Pointe Scientific) following the procedure of Allain et al. (1974).

Plasma fatty acids were analyzed as butyl esters and prepared as described for milk samples, with some modifications. One milliliter of plasma was transferred into 13×100 -mm extraction tubes with Teflon-lined screw caps, followed by the addition of $750 \mu\text{L}$ of butanol and $25 \mu\text{L}$ of internal standard (nonadecanoic acid, Nu-Chek Prep Inc.) and vortexed for 20 s. Samples were vortexed at low speed while slowly adding $500 \mu\text{L}$ of acetyl chloride; tubes were gassed with N_2 , capped tightly, and heated at 100°C for 90 min. After samples cooled to room temperature, 5 mL of $6\% \text{ K}_2\text{CO}_3$ was added and the samples were vortexed for 30 s. Then, 1 mL of hexane was added and samples were vortexed for another 30 s. Samples were then centrifuged for 25 min at $2,700 \times g$, and the bottom layer was aspirated and discarded. The remaining layer was washed 4 times with distilled deionized water and centrifuged for 20 min at $2,700 \times g$. The upper layer was removed and placed in injection vials for GC analysis.

All samples prepared as fatty acids esters were analyzed by GC in a chromatograph equipped with a flame-ionization detector and an autoinjector (Hewlett Packard model 6890, Hewlett Packard, Palo Alto, CA). Fatty acids were separated using a CP-Sil 88 fused silica capillary column ($100 \text{ m} \times 0.25 \text{ mm}$, i.d. $\times 0.20 \mu\text{m}$ film thickness; Varian Inc., Lake Forest, CA). The split ratio at the injector port was set at 100:1 with He as a carrier at a column flow of 2 mL/min . The column temperature was held at 50°C for 1 min after

the injection, then increased at 5°C/min to 145°C , held at 145°C for 30 min, increased to 190°C at 10°C/min , and held at 190°C for 30 min. Finally, the temperature was increased at 5°C/min to 210°C and held at this temperature for 40 min. The injection and detector temperatures were 230°C . Individual fatty acids were identified by order of elution and comparison to known commercially prepared reference standards (GLC-606 and GLC-566, Nu-Chek Prep Inc.).

Energy Balance Calculations

Energy values were calculated as follows: milk NE_L (Mcal/d) = [milk yield (kg) $\times$ ($0.0929 \times \% \text{ fat} + 0.0563 \times \% \text{ true protein} + 0.0395 \times \% \text{ lactose}$); (NRC, 2001; page 19, equation 2-15); the maintenance requirement was calculated as NE_M (Mcal/d) = $[0.08 \times \text{BW}^{0.75}]$. The NE_L (empty BW change) calculated according to (NRC, 2001) from the following equations: total reserves energy (Mcal/kg) = [proportion empty body fat $\times 9.4$ + proportion of empty body protein $\times 5.55$] (NRC, 2001; page 24, equation 2-23). The proportion of empty body fat was calculated as $= 0.037683 \times \text{BCS}(9)$ (NRC, 2001; page 22, equation 2-20), and proportion of empty body protein = $0.200886 - 0.0066762 \times \text{BCS}(9)$ (NRC, 2001; page 22, equation 2-21), and the $\text{BCS}(9)$ is $= \{[(\text{dairy BCS} - 1) \times 2] + 1\}$ (NRC, 2001; page 22, equation 2-22). The NE_L from body reserves were calculated by converting tissue energy per kilogram of empty BW (**EBW**) into tissue energy per kilogram of BW ($\text{EBW} \times 0.855$) and then converting to dietary NE_L using an efficiency of 0.82 for converting tissue energy from live weight loss to dietary NE_L , and an efficiency of 1.12 for converting dietary NE_L to tissue energy for live weight gain (NRC, 2001; page 24). Total NE_L (Mcal/d) = sum [NE_L (milk) + NE_M (maintenance) + NE_L (EBW change)]. Estimated diet NE_L = [total NE_L (Mcal/d)/DMI (kg)].

Statistical Analysis

Data for DMI, diet composition, milk production and composition, energy values, blood metabolites, and fatty acid compositions of milk and plasma were analyzed as a replicated 4×4 Latin square using the MIXED procedure of SAS (version 9.1, SAS Institute, Cary, NC). Cow within breed was designated as a random effect in the model. The statistical model was $Y_{ijkl} = \mu + T_i + P_j + C_{kl} + B_l + e_{ijkl}$, where μ = mean, T_i = treatment effect ($i = 1, 2, 3$, and 4), P_j = period effect ($j = 1, 2, 3$, or 4), C_{kl} = cow effect within breed, B_l = breed effect ($l = \text{Brown Swiss or Holstein}$), and e_{ijkl} = residual (error). Breed effects and interaction terms (treatment $\times$ breed, treatment $\times$ period, breed

Table 3. Nutrient composition of corn germ, alfalfa hay and corn silage (n = 4)¹

Item	CG	Forage	
		Alfalfa hay	Corn silage
DM, %	95.0 (0.22) ²	91.7 (1.09)	27.2 (0.74)
CP, % of DM	15.8 (0.23)	24.3 (0.64)	8.4 (0.18)
NDF, % of DM	22.8 (0.59)	36.9 (0.82)	47.7 (2.17)
ADF, % of DM	6.0 (0.18)	25.3 (0.88)	26.8 (0.53)
NFC, ³ % of DM	36.0 (0.67)	27.6 (0.81)	35.7 (2.25)
Starch, ⁴ % of DM	24.2	5.2	25.0
Ether extract, % of DM	19.9 (0.11)	2.6 (0.13)	3.7 (0.17)
Ca, ⁴ % of DM	0.02	1.39	0.34
P, ⁴ % of DM	1.13	0.30	0.13
Mg, ⁴ % of DM	0.49	0.36	0.17
NE _L , ⁵ Mcal/kg	2.39	1.38	1.39

¹Number of samples used for each analysis; each sample was run as duplicate.²Standard deviation in parentheses.³NFC = 100 - (% NDF + % CP + % ether extract + % ash).⁴Single sample analysis.⁵Calculated using NRC (2001).

× period, and treatment × breed × period) were tested but were not included in the model unless found to be significant. Data for 1 cow were deleted from the first period because the cow had problems with adaptation to Calan doors. Three polynomial contrasts (linear, quadratic, and cubic) were used to test the effect of feeding increasing concentrations of corn germ to dairy cows. Significance was declared at $P \leq 0.05$, and a tendency was reported if $0.05 < P \leq 0.10$. Declaring a linear, quadratic or a cubic response as a pattern that best fit the data was based on acceptance of the pattern with the smallest P -value if 2 of the 3 polynomial contrasts were significant ($P < 0.05$), unless the lack of fit test proved otherwise, which was conducted as described by Kaps and Lamberson (2004). If P -values were similar for 2 of the 3 polynomial contrasts, the higher order polynomial contrast was chosen to better fit the model.

RESULTS

CG and Dietary Treatments

Nutrient composition of CG, alfalfa hay, and corn silage are presented in Table 3. Corn germ used in the current experiment was obtained from a dry milling processor, and it contained (DM basis) 15.8% CP, 22.8% NDF, 24.2% starch, and 19.9% EE. The phosphorus concentration in CG was 1.13%, which is 4.3 times greater than that of corn. The predicted value for NE_L of the germ was estimated to be 2.4 Mcal/kg (NRC, 2001). Fatty acid composition of CG is presented in Table 4, and CG contained 17.9% total fatty acids (DM basis), with 53.2% linoleic acid (C18:2), 25.3%

oleic acid (C18:1), and 11.4% palmitic acid (C16:0). The fat concentration in CG obtained from dry grind or dry milling processes is less than that obtained from wet milling, which is attributed to differences in separation efficiency between the processes. In dry milling, separation of corn components is not as complete as in wet milling; therefore, small amounts of pericarp and endosperm remain attached to the germ, which decreases its fat concentration (Rausch and Belyea, 2006). The NDF content of the diets was increased as the concentration of CG incrementally increased across diets (Table 2). This is because the NDF content of CG is 3 and 1.6 times greater than that of corn and soybean meal, respectively. The starch and nonfibrous carbohydrate content of the diet were decreased as CG increased in the diets. Phosphorus concentration of CG is 3.7 times greater than that of corn; therefore, dietary P concentration was increased as the concentration of CG increased in the diet. Diet concentrations were in excess of the NRC (2001) recommendations for P concentration. The EE content of the diet increased from 4.8% DM in the control diet to 8.2% DM in the 21% CG diet. Consistent with the EE concentrations, the concentrations of total fatty acids linearly increased ($P < 0.001$) as CG increased from 0 to 21% of diet DM (Table 4). Increasing the concentration of CG in the diets linearly decreased ($P < 0.001$) the concentration of C16:0 and increased the concentrations of C18:2 n-6 and total C18:1 fatty acid (Table 4).

DMI, Milk Yield, and Milk Composition

Inclusion of CG resulted in a quadratic pattern in daily DMI, which was maximized when cows were fed

Table 4. Fatty acid composition of corn germ, forages, and dietary treatments (n = 4)¹

Item	CG	Forage		Dietary treatment (% CG)			
		Alfalfa hay	Corn silage	0	7	14	21
Total fatty acids, g/100 g of DM	17.9	1.7	1.8	3.7	5.0	6.3	7.5
Fatty acid, g/100 g of FA							
C14:0	0.5	7.5	9.5	1.0	0.8	0.7	0.6
C14:1 <i>trans</i> -9	ND ²	0.4	0.6	0.2	0.2	0.1	0.1
C14:1 <i>cis</i> -9	0.1	0.2	0.6	0.6	0.5	0.4	0.3
C16:0	11.4	24.6	15.5	17.0	15.4	14.8	14.0
C16:1 <i>trans</i> -9	0.2	1.0	1.1	0.4	0.3	0.3	0.2
C16:1 <i>cis</i> -9	1.0	2.1	0.5	2.5	2.1	1.4	1.1
C18:0	1.7	4.4	1.9	3.2	2.9	2.7	2.5
C18:1 total	25.3	13.5	15.2	22.1	23.3	24.1	24.6
Nonconjugated C18:2							
<i>Trans</i> -9, <i>trans</i> -12	0.1	1.1	1.3	0.1	0.1	0.1	0.1
<i>Cis</i> -9, <i>cis</i> -12	53.2	16.5	26.6	38.7	41.7	44.3	46.9
C18:3 n-6	0.4	2.5	2.6	1.4	1.4	1.1	0.9
C18:3 n-3	2.9	14.5	8.0	7.7	7.1	5.4	4.5
C20:0	0.4	1.4	0.5	0.6	0.5	0.5	0.5
Other fatty acids ³	2.7	10.5	16.2	4.0	3.4	3.6	3.2

¹Number of samples used for each analysis.²ND = not detectable.³Other fatty acids = sum of (C15:0, C15:1, C17:0, C17:1, C20:1, C20:2, C20:3, C20:4, C22:0, C22:1, C22:2, C22:5, C22:6).

the 7 and 14% CG diets and then declined when CG was included at 21% of diet DM (Table 5). Feeding increasing concentrations of CG resulted in a linear increase in intake of EE, total fatty acids, and saturated and unsaturated fatty acids. Milk production and ECM were increased quadratically as the concentrations of CG increased in the diets. Cows fed the 7 and 14% CG diets had numerically greater milk yield and ECM values compared with those fed the 21% CG diet. Feed efficiency expressed as ECM/kg of DMI was not different among dietary treatments; however, there was a breed effect as Holstein cows expressed a tendency ($P = 0.08$) for greater feed efficiency compared with Brown Swiss (1.50 vs. 1.30 for Holstein and Brown Swiss, respectively). A quadratic relationship between concentrations of CG and milk fat percentage was found, with milk fat percentage being numerically lower for cows fed the 21% CG compared with the other dietary treatments. Milk fat yield also increased in a quadratic manner as concentrations of CG increased, with milk fat yield being greatest for cows fed the 14% CG diet. Feeding increasing concentrations of CG resulted in a linear decrease in milk protein percentage, and a tendency for milk protein yield to decrease linearly with increasing CG in the diets. Increasing CG in dairy cow diets had no adverse effect on lactose yield or MUN; however, a cubic effect was observed in milk lactose percentage in response to dietary treatments. The lactose response reflected a numerically inverse relationship to milk fat percentage although the milk fat response was not determined to have a cubic response to diet CG. Lactose

concentrations were greater (4.83 vs. 4.59; $P < 0.01$) in milk from Holstein cows compared with milk from Brown Swiss. Milk from Brown Swiss cows had greater concentrations of MUN compared with milk from Holstein cows (14.47 vs. 11.83; $P < 0.01$). Although N in milk tended to decrease linearly as the concentration of CG increased in the diets, the efficiency of N utilization was not affected by dietary treatments; however, Holstein cows tended ($P = 0.10$) to have greater N efficiency when compared with Brown Swiss cows (0.27 vs. 0.24; respectively).

All cows among dietary treatments had similar BW and BCS (Table 6). Feeding CG resulted in a quadratic relationship between CG concentration in the diet and milk energy, and cows fed 21% CG had numerically the least milk energy compared with those fed the other dietary treatments. Neither NE_M nor $EBW\ NE_L$ was affected by dietary treatments. The estimated dietary NE_L was linearly increased with increasing CG in the diets.

Milk Fatty Acid Profiles

The fatty acid composition of milk fat is presented in Tables 7, 8, and 9. The concentrations of C14:0 and C16:0 fatty acids were decreased linearly, whereas those of C18:0, total C18:1, and *cis*-9, *cis*-12 C18:2 fatty acids were increased linearly as CG concentration increased across dietary treatments (Table 7). The ratio of n-6 to n-3 fatty acids was linearly increased mainly because of the linear increase in the concentrations of C18:2 fatty

Table 5. Least squares means for intake, milk yield, and milk composition by dairy cows fed increasing concentrations of corn germ (CG)

Item	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
DMI, kg/d	28.1	29.1	28.8	27.3	1.02	0.31	0.03	0.90
Ether extract intake, kg/d	1.3	1.7	2.0	2.3	0.07	<0.001	0.002	1.00
FA intake, ² kg/d	1.1	1.4	1.7	1.9	0.06	<0.001	0.02	0.71
SFA intake, ² g/d	216.7	261.4	317.0	326.6	10.34	<0.001	0.003	0.03
UFA intake, ² g/d	819.7	1123.4	1340.9	1524.4	44.70	<0.001	0.02	0.64
Milk, kg/d	37.3	38.0	38.2	36.3	1.42	0.25	0.03	0.55
ECM, ³ kg/d	39.5	39.8	40.4	36.2	1.53	0.03	0.02	0.25
FCM, kg/d	35.8	36.3	37.0	32.5	1.45	0.03	0.01	0.21
ECM/DMI	1.43	1.38	1.45	1.33	0.08	0.37	0.56	0.28
Fat, %	3.72	3.72	3.78	3.30	0.13	0.02	0.04	0.24
Fat, kg/d	1.39	1.41	1.45	1.19	0.07	0.02	0.01	0.18
Protein, %	3.46	3.37	3.32	3.37	0.06	0.04	0.05	0.76
Protein, kg/d	1.29	1.28	1.27	1.22	0.05	0.07	0.55	0.76
Lactose, %	4.74	4.74	4.59	4.76	0.05	0.55	0.03	<0.01
Lactose, kg/d	1.77	1.80	1.79	1.72	0.07	0.23	0.11	0.93
SCS ⁴	3.53	3.96	3.88	4.06	0.40	0.14	0.59	0.46
MUN, mg/dL	13.40	12.37	13.25	13.45	0.52	0.58	0.15	0.15
N intake, g/d	781.2	805.3	795.7	756.9	29.00	0.23	0.04	0.95
N milk, g/d	202.5	200.0	199.0	191.6	8.56	0.07	0.55	0.67
N utilization, ⁵ g/d	0.26	0.25	0.25	0.26	0.01	0.71	0.24	0.73

¹Contrasts: L = linear, Q = quadratic, and C = cubic.

²FA = fatty acids; SFA = saturated FA = sum of the intake of (C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, C22:0); UFA = unsaturated FA = sum of the intake of (C14:1, C15:1, C16:1, C17:1, C18:1, C18:2, C18:3, C20:1, C20:2, C20:3, C20:4, C22:1, C22:2, C22:5, C22:6).

³ECM = [(0.327 × milk yield (kg)) + (12.95 × fat yield (kg)) + (7.2 × protein yield (kg))]; Orth (1992).

⁴SCS = $\log_2(\text{SCC}/100,000) + 3$.

⁵N utilization = [(milk protein yield/6.38)/(protein intake/6.25)].

acids and the linear decrease in the concentration of C18:3 (n-3). Grouping fatty acids based on their origin (Table 8) showed that feeding increasing concentrations of CG resulted in a linear decrease in the concentration of de novo synthesized fatty acids (<16 carbon), a linear increase in the concentration of preformed fatty acids (>16 carbon), and a linear decrease in those fatty

acids derived from both sources (16-carbon). The yields of both de novo synthesized and the 16-carbon fatty acids were linearly decreased as the concentration of unsaturated fatty acid from CG increased in the diets (Table 9); however, the yield of preformed fatty acids was quadratically increased as the concentrations of CG increased in the diets. Feeding increasing concentrations

Table 6. Least squares means for BW, BCS, and energy values

Item	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
BW, kg	694	695	705	699	18.5	0.56	0.70	0.52
BW change, kg	9.7	-1.1	16.5	26.3	12.3	0.19	0.37	0.48
BCS	3.4	3.4	3.4	3.3	0.1	0.94	0.30	0.51
BCS change	-0.01	0.03	0.05	-0.03	0.05	0.87	0.21	0.68
Energy								
Milk NE _L , ² Mcal/d	27.5	27.7	28.0	25.1	1.1	0.02	0.03	0.28
Maintenance NE _M , ³ Mcal/d	11.9	11.9	12.0	11.9	0.2	0.58	0.71	0.53
NE _L ⁴ empty BW change, Mcal/d	1.4	0.7	2.4	2.7	1.0	0.18	0.61	0.34
Total NE _L , ⁵ Mcal/d	43.9	42.3	46.1	42.2	1.5	0.77	0.25	<0.01
Estimated diet NE _L , ⁶ Mcal/d	1.51	1.52	1.63	1.67	0.07	0.02	0.77	0.47

¹Contrasts: L = linear, Q = quadratic, and C = cubic.

²NE_L (milk) (Mcal/d) = milk yield (kg) × (0.0929 × fat% + 0.0563 × true protein% + 0.0395 × lactose%); NRC, (2001).

³NE_M (maintenance) (Mcal/d) = 0.08 × BW^{0.75}.

⁴NE_L (empty BW change) calculated according to NRC (2001).

⁵Total NE_L (Mcal/d) = sum [NE_L (milk) + NE_M (maintenance) + NE_L (empty BW change)].

⁶Estimated diet NE_L = [Total NE_L (Mcal/d)/DMI (kg)].

Table 7. Fatty acid composition of milk from cows fed increasing concentrations of corn germ (CG)

Fatty acid, g/100 g	Dietary treatment (% CG)					Contrast (<i>P</i> -value) ¹		
	0	7	14	21	SEM	L	Q	C
C4:0	2.93	2.88	3.04	2.51	0.11	<0.01	<0.01	0.01
C5:0	0.10	0.09	0.09	0.10	0.005	0.47	0.14	0.68
C6:0	1.84	1.75	1.76	1.35	0.07	<0.01	<0.01	0.02
C7:0	0.029	0.028	0.022	0.018	0.003	<0.01	0.46	0.48
C8:0	1.49	1.38	1.34	1.00	0.06	<0.01	<0.01	0.02
C9:0	0.06	0.06	0.05	0.07	0.02	0.73	0.40	0.54
C10:0	3.55	3.15	2.90	2.18	0.15	<0.01	0.07	0.12
C11:0	0.35	0.32	0.27	0.21	0.01	<0.01	0.06	0.99
C11:1 <i>cis</i> -10	0.10	0.09	0.06	0.05	0.01	<0.01	0.84	0.32
C12:0	4.34	3.76	3.33	2.74	0.18	<0.01	0.99	0.48
C12:1 <i>cis</i> -11	0.14	0.12	0.09	0.08	0.01	<0.01	0.33	0.40
C13:0	0.14	0.13	0.09	0.09	0.01	<0.01	0.53	0.11
C14:0	11.79	10.62	9.75	8.96	0.27	<0.01	0.32	0.80
C14:1 <i>trans</i> -9	0.20	0.18	0.16	0.14	0.01	<0.01	0.80	0.48
C14:1 <i>cis</i> -9	1.70	1.60	1.35	1.49	0.09	<0.01	0.10	0.10
C15:0	1.01	1.00	0.81	0.82	0.05	<0.01	0.89	0.08
C15:1 <i>cis</i> -14	0.25	0.20	0.21	0.17	0.01	<0.01	0.61	0.03
C16:0	28.74	26.58	24.04	23.34	0.71	<0.01	0.06	0.20
C16:1 <i>trans</i> -9	0.14	0.15	0.15	0.17	0.01	<0.01	0.72	0.25
C16:1 <i>cis</i> -9	1.73	1.73	1.45	1.76	0.12	0.65	0.10	0.04
C17:0	0.48	0.46	0.43	0.40	0.01	<0.01	0.78	0.91
C17:1 <i>cis</i> -10	0.11	0.11	0.09	0.10	0.01	0.15	0.44	0.02
C18:0	7.54	8.29	9.78	10.12	0.45	<0.01	0.64	0.33
C18:1 total	23.60	26.90	29.86	32.62	0.81	<0.01	0.57	0.95
C18:2 <i>trans</i> -9, <i>trans</i> -12	0.12	0.11	0.08	0.10	0.01	0.04	0.22	0.15
C18:2 <i>cis</i> -9, <i>cis</i> -12	2.93	3.37	3.67	3.82	0.10	<0.01	0.09	0.96
C18:3 n-6	0.04	0.05	0.04	0.03	0.01	<0.01	0.03	0.27
C18:3 n-3	0.53	0.51	0.46	0.44	0.02	<0.01	0.92	0.45
C20:0	0.16	0.17	0.17	0.17	0.01	0.23	1.00	0.87
C20:1	0.26	0.31	0.35	0.36	0.02	<0.01	0.02	0.70
C20:2	0.04	0.06	0.05	0.04	0.01	0.89	0.13	0.57
C20:3 n-6	0.13	0.13	0.12	0.11	0.01	<0.01	0.12	0.72
C20:3 n-3	0.04	0.04	0.06	0.08	0.01	<0.01	0.11	0.66
C20:4 n-6	0.26	0.25	0.25	0.23	0.01	0.04	0.25	0.53
C20:5 n-3	0.09	0.05	0.05	0.02	0.01	<0.01	0.90	0.20
Other FA ²	0.98	0.91	0.84	0.78	0.04	<0.01	0.95	0.92
Ratio of n-3:n-6 fatty acids	5.24	6.52	7.41	8.10	0.24	<0.01	0.18	0.84

¹Contrasts: L = linear, Q = quadratic, and C = cubic.²Other FA = sum of (unidentified fatty acids, C19:0, C19:1).

of CG resulted in a linear decrease in the concentrations of saturated fatty acids (**SFA**) and a linear increase in milk fat concentration of both monounsaturated fatty acids (**MUFA**) and PUFA (Table 8). The concentrations of total *trans*-18:1 and total *cis*-18:1 isomers in milk were linearly increased as CG increased in the diets (Table 8). The addition of CG to diets resulted in pronounced changes in milk fat concentrations of specific *trans* and *cis* isomers of octadecanoic acid. Milk fat concentrations of *trans*-9 and *trans*-10 C18:1 fatty acids were increased linearly with increasing CG concentration in the diets. The concentration of *trans*-10 C18:1 isomer in milk fat from cows fed the 7, 14, and 21% CG diets was 25, 42, and 158% greater, respectively, than those fed the control diet. Feeding CG resulted in a linear increase in the concentrations of *trans*-11 C18:1, and the concentration in milk fat from cows fed the 21% CG diet was 49% greater than the control diet.

When milk fatty acids were expressed on grams per day basis (Table 9), feeding increasing concentrations of CG resulted in a linear increase in the yield of *trans*-10 C18:1 isomer; however, a positive quadratic response in the yield of *trans*-11 C18:1 was found, with cows fed the 21% CG diet having a numerically lower yield than those fed the other dietary treatment.

Corn germ fed at increasing concentrations of dietary DM resulted in a linear increase in concentrations of milk conjugated C18:2 isomers (Table 8). Milk fat concentrations of the predominant CLA isomer *cis*-9, *trans*-11 linearly increased from 0.72% in cows fed the control diet to 1.13% of total milk fatty acids for those fed the 21% CG diet. This difference accounted for a 57% increase in the concentration of milk fat *cis*-9, *trans*-11 CLA isomer; however, milk fat concentration of *cis*-9, *trans*-11 CLA from cows fed the 21% CG diet was only 16% greater than that obtained in milk fat

Table 8. Isomers of C18:1 and conjugated linoleic acid (CLA) and unsaturation classes of fatty acids in milk of cows fed increasing concentrations of corn germ (CG)

Fatty acid, g/100 g	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
Total <i>trans</i>	2.16	2.64	3.24	3.96	0.15	<0.01	0.27	0.96
C18:1 <i>trans</i> -4	0.002	0.006	0.017	0.015	0.004	<0.01	0.31	0.14
C18:1 <i>trans</i> -6	0.08	0.13	0.13	0.15	0.01	<0.01	0.20	0.22
C18:1 <i>trans</i> -9	0.16	0.22	0.27	0.32	0.01	<0.01	0.85	0.85
C18:1 <i>trans</i> -10	0.59	0.74	0.84	1.52	0.11	<0.01	0.01	0.19
C18:1 <i>trans</i> -11	1.32	1.56	1.98	1.96	0.11	<0.01	0.12	0.10
Total <i>cis</i>	21.44	24.25	26.62	28.65	0.80	<0.01	0.36	0.95
C18:1 <i>cis</i> -6	0.17	0.22	0.27	0.32	0.01	<0.01	0.48	0.89
C18:1 <i>cis</i> -9	19.00	21.37	23.42	25.38	0.77	<0.01	0.61	0.90
C18:1 <i>cis</i> -11	0.86	0.90	0.93	1.07	0.06	<0.01	0.34	0.63
C18:1 <i>cis</i> -12	0.47	0.62	0.74	0.67	0.03	<0.01	<0.01	0.12
C18:1 <i>cis</i> -13	0.44	0.53	0.59	0.56	0.02	<0.01	<0.01	0.25
C18:1 <i>cis</i> -15	0.31	0.38	0.39	0.44	0.02	<0.01	0.52	0.17
Other <i>cis</i> -C18:1	0.19	0.24	0.28	0.24	0.02	<0.01	<0.01	0.35
Conjugated C18:2								
<i>Trans</i> -10, <i>cis</i> -12	0.10	0.12	0.13	0.20	0.01	<0.01	0.08	0.42
<i>Cis</i> -9, <i>trans</i> -11	0.72	0.86	0.97	1.13	0.05	<0.01	0.83	0.61
Other CLA isomers	0.21	0.27	0.32	0.33	0.03	<0.01	0.22	0.53
De novo ²	30.11	27.46	25.40	22.10	0.69	<0.01	0.22	0.53
Preformed ²	39.21	44.01	48.86	52.64	1.10	<0.01	0.44	0.71
C16 carbon ²	30.68	28.54	25.73	25.36	0.77	<0.01	0.04	0.11
SCFA ³	6.44	6.19	6.29	5.05	0.21	<0.01	<0.01	0.02
MCFA ³	55.00	50.39	45.34	42.84	1.06	<0.01	0.12	0.31
LCFA ³	38.58	43.44	48.37	52.14	1.10	<0.01	0.42	0.68
SFA ⁴	64.69	60.85	58.05	54.26	0.93	<0.01	0.97	0.46
MUFA ⁴	29.18	32.29	34.61	37.47	0.83	<0.01	0.98	0.48
PUFA ⁴	6.15	6.87	7.34	8.03	0.23	<0.01	0.94	0.54

¹Contrasts: L = linear, Q = quadratic, and C = cubic.

²Fatty acids (FA) based on their origin; de novo = FA <C16 carbon, performed = FA >C16 carbon, and FA from both origin = C16 carbons.

³Fatty acids based on their chain length; SCFA = short-chain FA (C4 to C9), MCFA = medium-chain FA (C10 to C16), and LCFA = long-chain FA (FA ≥ C17).

⁴FA based on their degree of saturation; SFA = saturated FA, MUFA = monounsaturated FA, and PUFA = polyunsaturated FA.

from cows fed the 14% CG diet. Similarly, milk fat concentrations of *trans*-10, *cis*-12 CLA also linearly increased in response to dietary treatments. Milk fat from cows fed the 21% CG diet contained numerically the greatest concentrations of *trans*-10, *cis*-12 CLA, which was 100, 67, and 54% greater than those obtained from cows fed the 0, 7, and 14% CG diets, respectively. Milk fat yield of *cis*-9, *trans*-11 CLA was linearly increased in response to increasing CG in the diets (Table 9). Cows fed the 14 and 21% CG diet produced numerically similar milk fat content of *cis*-9, *trans*-11 CLA, which averaged 13.7 g/d (Table 9). Milk fat yield of *trans*-10, *cis*-12 CLA was also linearly increased from 1.4 g/d on the control diet to 2.3 g/d when cows were fed the 21% CG diet.

Plasma Metabolites and Fatty Acids Composition

Adding CG had no effect on glucose, triglyceride, and BHBA plasma concentrations; however, feeding increas-

ing concentrations of CG resulted in a linear increase in the concentration of blood NEFA and tended to linearly increase the concentration of cholesterol (Table 10). Feeding increasing concentrations of CG caused an alteration in plasma fatty acids composition (Tables 11 and 12). Feeding CG at 0, 7, 14, and 21% of dietary DM resulted in a linear decrease in the concentrations of C14:1 isomers and a cubic effect on the concentrations of C16:0 (Table 11). Increasing CG in the diets resulted in a linear increase in plasma concentrations of C18:0, C18:1, and *cis*-9, *cis*-12 C18:2 fatty acids. Plasma concentrations of both *trans*-10 and *trans*-11 C18:1 were linearly increased (Table 12). The concentration of plasma *trans*-10, *cis*-12 CLA was linearly increased in response to increasing CG in the diets. There was a 93% increase in plasma concentration of *trans*-10, *cis*-12 CLA when cows were fed the 21% CG diet compared with those fed the 0% CG diet; however, feeding CG had no effect on plasma concentration of *cis*-9, *trans*-11 CLA isomer. The plasma concentration of SFA tended

Table 9. Daily production of C18:1 and conjugated linoleic acid (CLA) isomers in milk fat, and normalized ratios of fatty acids (FA) in milk from cows fed increasing concentrations of corn germ (CG)

Fatty acid, g/d	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
Total <i>trans</i>	29.2	36.9	45.9	46.7	2.5	<0.01	0.09	0.30
C18:1 <i>trans</i> -4	0.02	0.08	0.24	0.20	0.05	<0.01	0.27	0.16
C18:1 <i>trans</i> -6	1.2	1.8	2.0	1.8	0.1	<0.01	<0.01	0.72
C18:1 <i>trans</i> -9	2.2	3.0	3.9	3.8	0.2	<0.01	<0.01	0.20
C18:1 <i>trans</i> -10	7.9	10.3	12.1	16.8	1.1	<0.01	0.18	0.40
C18:1 <i>trans</i> -11	17.8	21.8	27.8	24.2	1.9	<0.01	0.03	0.14
Total <i>cis</i>	294.9	340.4	386.6	343.0	19.7	<0.01	<0.01	0.16
C18:1 <i>cis</i> -6	3.3	3.1	3.9	3.6	0.2	<0.01	<0.01	0.15
C18:1 <i>cis</i> -9	261.5	299.5	339.8	303.6	17.2	<0.01	<0.01	0.16
C18:1 <i>cis</i> -11	11.7	12.6	13.6	12.7	1.0	0.26	0.25	0.62
C18:1 <i>cis</i> -12	6.5	8.9	10.8	8.2	0.7	<0.01	<0.01	0.11
C18:1 <i>cis</i> -13	6.1	7.5	8.8	6.9	0.5	0.07	<0.01	0.12
C18:1 <i>cis</i> -15	4.3	5.4	5.7	5.2	0.4	0.02	<0.01	0.92
Other <i>cis</i> C18:1	2.5	3.4	4.1	2.8	0.3	0.23	<0.01	0.16
Conjugated C18:2								
<i>Trans</i> -10, <i>cis</i> -12	1.4	1.6	1.9	2.3	0.2	<0.01	0.66	0.82
<i>Cis</i> -9, <i>trans</i> -11	9.8	12.1	13.7	13.7	1.0	<0.01	0.17	0.74
Other CLA isomers	2.8	3.8	4.2	3.8	0.4	<0.01	0.02	0.83
De novo	421.4	386.0	367.1	262.8	20.2	<0.01	0.02	0.14
Preformed	539.6	617.8	709.6	632.1	34.9	<0.01	<0.01	0.15
C16 carbons	430.9	403.4	372.8	299.9	22.5	<0.01	0.15	0.58
Short-chain FA	89.8	87.2	90.0	61.6	5.3	<0.01	<0.01	0.07
Medium-chain FA	779.8	719.0	665.0	512.8	36.5	<0.01	0.08	0.37
Long-chain FA	522.4	601.7	694.8	620.5	34.4	<0.01	<0.01	0.15
Saturated FA	905.1	858.0	842.9	649.9	44.6	<0.01	0.04	0.19
Monounsaturated FA	402.4	453.5	501.7	448.9	23.9	0.02	<0.01	0.21
Polyunsaturated FA	84.5	96.3	105.4	96.1	5.5	0.03	0.02	0.44
Desaturase index ²								
C14:1/C14:0	0.13	0.13	0.12	0.14	0.01	0.03	0.13	0.05
C16:1/C16:0	0.06	0.06	0.06	0.07	0.01	<0.01	0.19	0.09
C18:1/C18:0	0.72	0.72	0.71	0.72	0.01	0.69	0.83	0.32
CLA/TVA ³	0.36	0.36	0.34	0.37	0.01	0.90	0.09	0.06

¹Contrasts: L = linear, Q = quadratic, and C = cubic.²Normalized ratio = product/[substrate + product] (Sol Morales et al., 2000).³CLA = *cis*-9, *trans*-11 CLA, and TVA (*trans* vaccenic acid) = *trans*-11 C18:1.

to quadratically increase, whereas the concentration of PUFA linearly increased as the concentration of supplemental fat from CG increased across treatments.

DISCUSSION

Replacing corn grain and soybean meal with CG at 0, 7, 14, and 21% of dietary DM resulted in increased

concentrations of dietary fat from CG, which was equal to 0, 1.4, 2.8, and 4.2% of additional fat, respectively. Dietary fat supplements are typically used in dairy cattle rations to increase the energy density of the diet and increase milk production (Palmquist, 1984; NRC, 2001; Litherland et al., 2005). Despite the potential of improving the energetic value of dairy cattle rations, supplemental dietary fat may decrease DMI when total

Table 10. Concentrations of glucose, NEFA, triglyceride, cholesterol, and BHBA in plasma of cows fed increasing concentrations of corn germ (CG)

Component	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
Glucose, mg/dL	70.4	69.7	68.0	67.3	1.2	0.17	1.00	0.80
NEFA, μ Eq/L	188.7	221.3	219.1	242.0	17.2	0.04	0.77	0.42
Triglyceride, mg/dL	16.4	16.8	15.5	15.2	1.5	0.43	0.78	0.62
Cholesterol, mg/dL	169.7	167.5	196.4	178.9	9.4	0.07	0.28	0.02
BHBA, mg/dL	7.4	7.7	7.3	7.1	0.4	0.39	0.18	0.94

¹Contrasts: L = linear, Q = quadratic, and C = cubic.

Table 11. Fatty acid composition of plasma from cows fed increasing concentrations of CG

Fatty acid, µg/mL	Dietary treatment (% CG)					Contrast (<i>P</i> -value) ¹		
	0	7	14	21	SEM	L	Q	C
C14:0	14.8	14.7	16.1	13.7	1.3	0.70	0.29	0.29
C14:1 <i>trans</i> -9	2.2	2.0	2.0	1.8	0.1	<0.01	0.87	0.37
C14:1 <i>cis</i> -9	9.0	8.8	9.2	8.0	0.5	<0.01	0.10	0.17
C16:0	250.4	254.2	290.6	262.1	10.6	0.07	0.07	0.02
C16:1 <i>trans</i> -9	6.1	5.8	6.5	6.4	0.6	0.40	0.86	0.37
C16:1 <i>cis</i> -9	18.9	19.1	22.0	21.4	1.5	0.09	0.79	0.31
C18:0	86.4	91.8	108.3	97.8	4.9	<0.01	0.05	0.04
C18:1 total	130.4	133.8	163.0	152.8	6.3	<0.01	0.21	0.01
Nonconjugated C18:2								
<i>Trans</i> -9, <i>trans</i> -12	6.4	7.7	7.0	6.7	0.8	0.91	0.25	0.42
<i>Cis</i> -9, <i>cis</i> -12	1,095.7	1,125.4	1,430.9	1,254.1	64.9	<0.01	0.03	<0.01
C18:3 n-6	21.6	19.0	21.8	18.8	1.9	0.25	0.74	0.07
C18:3 n-3	78.1	67.9	73.7	60.0	4.0	<0.01	0.51	<0.01
C20:0	1.7	1.7	1.9	1.9	0.1	0.04	0.82	0.20
C20:1	2.2	2.6	3.1	3.6	0.3	<0.01	0.96	0.34
C20:2	2.6	3.1	2.8	2.5	0.3	0.70	0.13	0.47
C20:3 n-6	55.4	52.5	59.5	52.0	4.0	0.79	0.39	0.04
C20:3 n-3	0.1	0.7	0.3	0.1	0.3	0.66	0.23	0.35
C20:4 n-6	43.0	45.6	54.4	48.1	2.9	0.04	0.08	0.06
C20:5 n-3	21.5	20.7	27.3	25.0	2.3	0.05	0.70	0.07
C22:1	0.3	0.2	0.2	0.2	0.1	0.36	0.95	1.00
C22:2	12.6	16.8	14.9	13.6	1.9	0.86	0.10	0.38
C22:3 n-3	5.4	4.4	5.2	4.4	0.8	0.44	0.85	0.34
C22:4 n-6	3.5	3.4	2.7	3.1	0.5	0.37	0.58	0.41
C22:5 n-6	12.9	12.0	14.9	12.9	0.9	0.27	0.36	0.01
C22:5 n-3	7.1	5.4	6.4	5.7	0.7	0.30	0.44	0.14
C22:6 n-3	6.6	5.8	8.0	6.9	0.6	0.07	0.83	0.01

¹Contrasts: L = linear, Q = quadratic, and C = cubic.

dietary level exceeds 7% DM (NRC, 2001). Supplementing diets with fat sources rich in unsaturated rather than saturated fatty acids is more likely to depress DMI (Firkins and Eastridge, 1994; Allen, 2000). Feeding CG at 7 and 14% of dietary DM resulted in a 3.6 and 2.4% increase in DMI, respectively, whereas feeding CG at 21% of dietary DM resulted in 2.9% decrease in DMI compared with the control diet. This decrease in DMI could have been related, in part, to a negative effect of dietary fat on rumen fermentation (Jenkins, 1993). A negative relationship was observed between dietary fatty acid content and DMI (Firkins and Eastridge, 1994); however, this relationship was not significant until the concentration of dietary fatty acids was 3.5 percentage units greater than that of the basal diet. In the current study, the control diet contained 3.7% total fatty acids on a DM basis. The addition of CG at 7, 14, and 21% DM accounted for 1.3, 2.6, and 3.8 percentage units of additional total fatty acids in the diets, respectively. Similar responses in DMI have been observed in previous studies when dietary fat was fed to, or abomasally infused into, lactating dairy cows (Drackley et al., 1992; Relling and Reynolds, 2007).

The response of milk production to dietary fat supplementation is dependent upon the composition of the basal diet, stage of lactation, energy balance, level and

source of dietary fat, and DMI (NRC, 2001). Milk production often increases in response to additional energy provided by fat supplementation in lactating dairy cow diets (NRC, 2001). The quadratic response observed in milk production is a typical response to dietary fat supplementation. Palmquist (1983) indicated that milk yield response to supplemental fat is curvilinear and decreases as the concentration of fat increases in the diet. The decrease in milk production when cows were fed 21% CG could be partially attributed to the decrease in DMI. Jenkins and Jenny (1992) indicated that when fat supplements fail to improve milk production, it can usually be related to negative effects of dietary fat on feed intake, rumen fermentation, or poor digestibility of fatty acids.

In the present study, inclusion of CG at increasing concentrations of dietary DM resulted in a linear decrease in milk protein percentage, with a tendency for a linear decrease in milk protein yield. Previous studies have shown that milk protein percentage often decreases when supplemental fat is fed to lactating dairy cows (DePeters and Cant, 1992; Wu and Huber, 1994), and the effect diminishes as the concentration of fat supplement increases in the diet (NRC, 2001). The linear decrease in milk protein percentage and the numeric decrease in yield, particularly when cows were

Table 12. Plasma C18:1 and conjugated linoleic acid (CLA) isomers from cows fed increasing concentrations of corn germ (CG)

Fatty acid (FA), µg/mL	Dietary treatment (% CG)				SEM	Contrast (<i>P</i> -value) ¹		
	0	7	14	21		L	Q	C
C18:1 <i>trans</i> -4	0.1	0.1	0.1	0.2	0.1	0.19	0.24	0.91
C18:1 <i>trans</i> -6	0.4	0.6	0.9	0.8	0.1	<0.01	0.18	0.51
C18:1 <i>trans</i> -9	0.1	0.2	0.4	0.6	0.2	0.16	0.62	0.82
C18:1 <i>trans</i> -10	1.1	1.4	1.3	2.0	0.3	0.03	0.42	0.32
C18:1 <i>trans</i> -11	6.5	8.2	9.3	8.8	0.8	<0.01	0.03	0.63
C18:1 <i>cis</i> -6	ND ²	ND	ND	ND				
C18:1 <i>cis</i> -9	101.0	105.6	125.9	118.1	4.9	<0.01	0.16	0.03
C18:1 <i>cis</i> -11	12.1	11.7	13.0	12.1	0.5	0.45	0.50	0.03
C18:1 <i>cis</i> -12	4.2	5.1	6.2	5.4	0.3	<0.01	<0.01	0.04
C18:1 <i>cis</i> -13	1.8	2.0	2.4	2.0	0.1	0.05	0.01	0.03
C18:1 <i>cis</i> -15	0.5	0.6	0.7	0.6	0.1	0.27	0.04	0.08
CLA isomers								
<i>Trans</i> -10, <i>cis</i> -12	1.4	1.7	2.2	2.7	0.3	<0.01	0.58	0.22
<i>Cis</i> -9, <i>trans</i> -11	1.3	1.2	1.6	1.3	0.2	0.54	0.48	0.11
Other CLA isomers	0.6	0.8	1.0	0.7	0.1	0.22	0.02	0.15
Saturated FA	444.0	452.3	500.1	461.6	18.0	0.12	0.10	0.07
Monounsaturated FA	423.3	435.3	493.9	454.6	29.0	0.13	0.27	0.18
Polyunsaturated FA	1,448.3	1,378.3	1,722.8	1,584.3	86.5	<0.01	0.63	0.02

¹Contrasts: L = linear, Q = quadratic, and C = cubic.²ND = not detectable.

fed the 21% CG diet, may be a function of decreased milk production rather than decreased milk protein production per se (DePeters and Cant, 1992; Shingfield et al., 2006).

Milk fat depression is often associated with diets containing greater concentrations of PUFA. Generally, increasing the amount of free or unesterified unsaturated fatty acids is more likely to cause milk fat depression (NRC, 2001). In the present study, a decrease in milk fat percentage and yield was not observed until CG was included at 21% of dietary DM; however, cows fed the 7 and 14% CG diets had numerically similar concentrations of milk fat compared with those fed the control diet. Data from the literature indicate that protected or saturated fat supplements tend to maintain or increase milk fat percentage (Palmquist and Jenkins, 1980; Delbecchi et al., 2001). Klopfenstein et al. (2008) indicated in their meta-analysis on studies conducted in feedlot steers, that the fat in distillers grains might be partially protected from ruminal biohydrogenation and can result in greater concentrations of unsaturated fatty acids leaving the rumen. In the present study, cows fed the 7 and 14% CG diets maintained milk production as well as milk fat percentage and yield, which might indicate that the fat in CG is relatively protected from rumen biohydrogenation. Maintaining milk fat percentage could result from an increased mammary gland uptake of LCFA that might exceed the depression in milk fat synthesis (Palmquist and Jenkins, 1980).

The numeric decrease in milk fat content when cows were fed 21% CG could be attributed to an increased dietary supply of unsaturated fatty acids, particularly

C18:2. Dietary unsaturated fatty acids are known to modify rumen lipid metabolism, leading to increased concentrations of unique biohydrogenation intermediates, which are very effective inhibitors of mammary gland de novo fatty acid synthesis (Bauman and Griinari, 2003). *Trans*-10 C18:1 and *trans*-10, *cis*-12 CLA are primary candidates to be associated with milk fat depression. Previous studies established that postruminal infusion of *trans*-10, *cis*-12 CLA can inhibit milk fat synthesis in dairy cows (Baumgard et al., 2001; Looor and Herbein 2003). Recently, Lock et al. (2007) concluded that *trans*-10 C18:1 does not decrease milk fat synthesis when infused abomasally; however, infusion of *trans*-10, *cis*-12 CLA resulted in a 27% decrease in milk fat content.

In the present study, feeding CG at 21% of dietary DM resulted in a 100% increase in the concentration of milk fat *trans*-10, *cis*-12 CLA compared with that observed in cows fed the control diet. A linear relationship was reported by de Veth et al. (2004) between the dose of *trans*-10, *cis*-12 CLA infused into the abomasum and the milk fat yield of *trans*-10, *cis*-12 CLA. Moreover, it has been demonstrated that, during diet-induced milk fat depression, the formation of *trans*-10, *cis*-12 CLA increases because of modifications in ruminal lipid metabolism (Bauman and Griinari, 2003; Shingfield et al., 2006). The linear increase in the concentration and yield of *trans*-10, *cis*-12 CLA observed in milk in the current study might indicate an increase in the concentration of *trans*-10, *cis*-12 CLA leaving the rumen. A similar linear response in plasma concentration of *trans*-10, *cis*-12 CLA was observed. Plasma from cows fed the

21% CG diet had a 98% increase in the concentration of *trans*-10, *cis*-12 CLA compared with those fed the control diet. The increase in plasma concentration of *trans*-10, *cis*-12 CLA also indicates an increase in the availability of *trans*-10, *cis*-12 CLA presented to the mammary gland to be incorporated in milk fat. In the current study, the decrease in milk fat percentage and yield could be related to the increased concentration of *trans*-10, *cis*-12 CLA; however, there are discrepancies in the relationship between milk fat concentration of *trans*-10, *cis*-12 CLA and the degree of milk fat depression as previously observed by Loores et al. (2002) and Peterson et al. (2003). These findings clearly suggest that other substances may be involved or that a critical concentration threshold was not exceeded. de Veth et al. (2004) indicated that a substantial decrease in milk fat yield occurs in response to small doses of *trans*-10, *cis*-12 CLA; however, increasing the infused amount of *trans*-10, *cis*-12 CLA beyond 6 g/d caused little or no further decrease in milk fat synthesis.

In the present study, the concentration of *trans*-10 C18:1 increased linearly from 0.59% in milk from cows fed the control diet to 1.52% for those fed the 21% CG diet. Cows fed the 21% CG diet had the greatest concentration of *trans*-10 C18:1 in milk fat, which was 105 and 81% greater than that obtained from cows fed the 7 and 14% CG diets, respectively. Plasma concentration of *trans*-10 C18:1 increased linearly as the concentration of CG increased. This could explain the linear increase in the yield of milk fat *trans*-10 C18:1. Although milk fat concentration of *trans*-10 C18:1 has been shown to increase during diet-induced milk fat depression, no direct relationship has been established between the depression of milk fat synthesis and milk fat concentration of this fatty acid. An increase in the concentration of both *trans*-10, *cis*-12 CLA and *trans*-10 C18:1 indicates that ruminal lipid metabolism had been modified, which shifted the biohydrogenation pathway toward the formation of *trans*-10 C18:1 (the increase in the concentrations of these 2 fatty acids has been reported to cause milk fat depression; Bauman and Griinari, 2003).

Peterson et al. (2003) reported that the relationship between milk fat concentration of *trans*-10, *cis*-12 CLA and the decrease in milk fat yield during diet-induced milk fat depression was not necessarily the same relationship observed during abomasal infusion of relatively pure *trans*-10, *cis*-12 CLA. Therefore, the involvement of other biohydrogenation intermediates containing conjugated bonds in milk fat depression has been hypothesized (Bauman and Griinari, 2003; Perfield et al., 2004). Shingfield et al. (2006) showed that milk fat content was inversely correlated ($r = -0.808$) with milk

fat concentration of *trans*-9, *cis*-11 CLA, and changes in this CLA isomer could account for approximately 80% of the variation in milk fat content when cows were fed a fish oil and sunflower oil diet. Perfield et al. (2007) demonstrated that *trans*-9, *cis*-11 CLA isomer can decrease milk fat content in abomasally infused cows. In the current study, the concentrations of the total unidentified CLA isomers linearly increased from 0.21% on the control diet to 0.33% on the 21% CG diet. A linear increase ($P < 0.01$) in the concentration of one of these unidentified CLA isomers was observed in the current study. Feeding increasing concentrations of CG at 0, 7, 14, and 21% resulted in a milk fat concentration of this unidentified CLA isomer of 0.04, 0.06, 0.07, and 0.09%, respectively. In the current study we could not identify this CLA isomer, but we speculated it could be the *trans*-9, *cis*-11 CLA.

In the present study, the plasma concentration of *trans*-11 C18:1 was linearly increased by increasing CG in the diets. Cows fed the 14% CG diet had numerically the greatest plasma concentration of *trans*-11 C18:1. This fatty acid is the primary precursor for endogenously synthesized *cis*-9, *trans*-11 C18:2 CLA isomer (Griinari et al., 1998). This increase in the plasma concentration of *trans*-11 C18:1 is indicative of an enhanced supply that will be available for endogenous synthesis of *cis*-9, *trans*-11 CLA in the mammary gland. A decline in *trans*-11 C18:1 in both plasma and milk was observed when cows were fed 21% CG, which was simultaneously associated with an increase of *trans*-10 C18:1 in the plasma and milk fat. This indicates a shift in the biohydrogenation process in the rumen, resulting in *trans*-10 C18:1 replacing *trans*-11 C18:1 as the predominant *trans*-C18:1 fatty acid. This shift in biohydrogenation pathways toward *trans*-10 C18:1 instead of *trans*-11 C18:1 in cows fed 21% CG could explain the numerically similar production of milk fat *cis*-9, *trans*-11 CLA when cows were fed the 14% CG diet.

Changes in milk fatty acid composition observed in this study are consistent with known effects of unsaturated fat supplements on de novo synthesis of fatty acids in the mammary gland (Palmquist et al., 1993). It is well established that feeding unsaturated oils is typically associated with a decrease in de novo synthesis of short-chain fatty acids (SCFA) and medium-chain fatty acids (MCFA; Litherland et al., 2005; Shingfield et al., 2006; Cruz-Hernandez et al., 2007). Ney (1991) indicated that the decrease in MCFA is an improvement in the profile of milk fatty acids, because they have been reported to constitute the hypercholesterolemic portion of milk fat. Milk fat C16:0 is derived either from the diet or can be de novo synthesized in the mammary gland (Grummer, 1993). The decrease in milk fat concentration of C16:0

in cows fed the CG diets compared with the control diet indicates a decrease in de novo synthesis of C16:0 in the mammary gland.

Concentrations of glucose in blood were not affected by feeding increasing concentrations of CG, which averaged 68.8 mg/dL. Grummer and Carroll (1991) indicated that fat supplementation might spare glucose, but it will not necessarily increase blood glucose concentration; however, spared glucose could be utilized for lactose synthesis and milk production. Feeding supplemental dietary fat is typically associated with an increase in NEFA and cholesterol concentration in plasma of dairy cows (Grummer and Carroll, 1991; Chilliard 1993; Drackley, 1999). Increases in plasma NEFA could be attributed to mobilization of adipose tissue or to a decrease in NEFA clearance by the tissues, or both (Grummer and Carroll, 1991). An increase in plasma NEFA attributable to mobilization of adipose tissue is more likely to be associated with a negative energy balance; however, in the present study cows were in a neutral or positive energy balance and the plasma NEFA concentrations were linearly increased as the concentration of CG increased in the diets. Therefore, this increase in plasma NEFA is more likely to be a result of inefficient uptake of fatty acids by peripheral tissue as has been proposed by Grummer (1993).

Plasma BHBA was not affected by feeding increasing concentrations of CG. Feeding supplemental fat in dairy cow diets has been reported to have minimal or no effect on plasma BHBA concentrations (Grummer and Carroll, 1991). The effect of added CG on plasma cholesterol concentration tended ($P = 0.07$) to be linear and agreed with previous studies that reported a positive relationship between serum cholesterol concentration and dietary fat (Palmquist and Conrad, 1978; Drackley et al., 1992). Previous findings by Khorasani et al. (1992) and Khorasani and Kennelly (1998) demonstrated a quadratic response in cholesterol concentration when canola seed was fed at increasing concentrations of the diet DM. Nestel et al. (1978) proposed that increasing dietary fat concentration may stimulate intestinal cholesterol synthesis to meet the demands for fat transport and absorption.

CONCLUSIONS

Results from the current study indicate the potential for CG to be included in dairy cow diets up to 14% of dietary DM with no adverse effect on DMI, milk yield, and milk composition. Cows fed 7 and 14% CG had numerically greater DMI and milk yield compared with those fed 21% CG. Feeding CG at 21% or greater concentration of dietary DM could negatively affect DMI, milk yield, and milk fat concentration. Inclusion of CG

in dairy cow diets increased milk fat concentrations of MUFA and PUFA in milk fat and the concentration of *cis*-9, *trans*-11 CLA. Overall, CG provides an alternative source of fat for energy in lactating dairy cows when fed up to 14% of dietary DM.

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