Milk Production and Composition from Cows Fed High Oil or Conventional Corn at Two Forage Concentrations¹

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ABSTRACT

Twelve multiparous Holstein cows (63 ± 24 d in milk) were used in a replicated 4×4 Latin square with 28-d periods to evaluate conventional and high oil corn grains when fed at two different forage-to-concentrate ratios. Dietary treatments consisted of conventional or high oil corn supplementing a diet with a 25:25:50 mixture of corn silage: alfalfa: concentrate mix, or a high forage diet with a 30:30:40 mixture of corn silage: alfalfa: concentrate mix. Dry matter intake (28.1, 28.7, 26.9, and 26.2 kg/d for normal diets with conventional and high oil corn, and high forage diets with conventional and high oil corn, respectively) and milk yields (36.8, 37.2, 35.5, and 35.2, kg/d) were similar for conventional and high oil corn diets and were lower with the high forage diet, regardless of corn source. Milk fat concentrations were greater when cows were fed diets containing 60% forage (4.03 vs. 3.88%, for the 60 and 50% forages, respectively), but milk protein concentrations were not affected by forage content. Corn source did not affect milk fat or protein concentrations. Long-chain fatty acid concentrations, unsaturated fatty acid concentrations, and total 18:1 fatty acid concentrations were greater when cows were fed high oil corn but were unaffected by forage content of the diet. Concentrations of transvaccenic acid (0.58, 0.81, 0.62, and 0.69 g/100 g of fatty acids) and *cis*-9, *trans*-11 conjugated linoleic acid (0.28, 0.39, 0.32, and 0.33 g/100 g of fatty acids) were greater when cows were fed high oil compared with conventional corn when fed 50% forage but were similar for both corn sources at 60% forage. Total n-3 fatty acids were not affected by corn source or forage content. High forage diets decreased milk production and increased milk fat concentration. Feeding high oil

corn increased concentrations of long-chain, unsaturated, transvaccenic, and conjugated linoleic fatty acids in milk; however, production of transvaccenic and conjugated linoleic acids were attenuated by high forage diet.

(Key words: milk, fatty acid, high oil corn, forage concentration)

Abbreviation key: CC = conventional corn, CLA = conjugated linoleic acid, HF = higher forage concentration diets, HFCC = higher forage concentration, conventional corn diet, HFHOC = higher forage concentration, high oil corn diet, HOC = high oil corn, LF = lower forage concentration diets, LFCC = lower forage concentration, conventional corn diet, LFHOC = lower forage concentration, high oil corn diet, TVA = vaccenic acid.

INTRODUCTION

Corn grain is extensively fed to lactating dairy cattle with many choices of corn hybrids currently available. High oil corn (HOC) is typically reported to contain 7 to 8% ether extract on a DM basis, nearly double the concentration found in conventional corn (CC) hybrids, while protein concentration is typically 1 to 2% units higher (Dado, 1999). Many studies have reported that high producing dairy cattle yield more milk when fed supplemental dietary fat (Palmquist and Jenkins, 1980; Casper and Schingoethe, 1989; Schingoethe and Casper, 1991). Using oilseeds such as soybeans or high oil corn as the fat source may slow the release of oil into the rumen and lessen ruminal biohydrogenation (Aldrich et al., 1997), which may minimize ruminal disturbances while still delivering fatty acids to the animal. Another potential advantage of HOC in diets of lactating cows receiving high quantities of corn grain is a slightly lower concentration of dietary starch, which may help decrease the incidence of acidosis (Dado, 1999; Andrae et al., 2000).

Research has either not shown an increase in milk production from HOC (Atwell et al., 1988; Elliott et al., 1993; Dhiman et al., 1999) or a tendency toward

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increased milk production (LaCount et al., 1995; Weiss and Wyatt, 2000). The experimental diets have typically contained adequate energy, which did not take advantage of the higher energy concentration of HOC. Although Weiss and Wyatt (2000) found no differences in DMI between CC silage and HOC silage, some studies (Atwell et al., 1988; LaCount et al., 1995) showed increased DMI when cows were fed HOC grain. Apparent DM digestibility was lower (73.3 vs. 69.7% for conventional and HOC grains, respectively) in the study by Atwell et al. (1988); however, another study noted no differences in nutrient digestibility (Elliott et al., 1993).

A current interest in milk fat manipulation is to produce milk with higher proportions of unsaturated fatty acids. Milk with higher proportions of unsaturated fat is likely to be preferred by the consumer because of concerns about too much saturated fat in the diet. An increase in saturated fatty acid intake has been linked to a rise in cardiovascular disease (Ashes et al., 1997). Dairy feeds that contain lipids with low susceptibility to ruminal biohydrogenation (e.g., oilseeds vs. free oil) can influence milk fatty acid composition (Grummer, 1991; Palmquist et al., 1993; Avila et al., 2000). Milk from cows fed high oil corn, an oilseed, has been shown to contain more unsaturated fatty acids than milk from cows fed CC (Elliott et al., 1993; LaCount et al., 1995).

The objective of this study was to compare conventional and high oil corn grains when fed at two different forage: concentrate ratios. Diets were formulated at a 50:50 ratio (lower forage concentration diets, **LF**) or a 60:40 ratio of forage to concentrate (higher forage concentration diets, **HF**) that contained equal amounts of either CC or HOC within forage concentration. The lower forage concentration, high oil corn diet (**LFHOC**) was formulated to contain the highest energy concentration, while the higher forage concentration, conventional corn diet (**HFCC**) was formulated to contain the lowest energy concentration. The lower forage concentration, conventional corn diet (**LFCC**) and the higher forage concentration, high oil corn diet (**HFHOC**) contained similar intermediate energy concentrations. The hypothesis being tested was whether the HOC could be used in a higher forage diet to maintain milk production and increase the concentration of unsaturated fatty acids in milk fat.

MATERIALS AND METHODS

Experimental Design and Data Collection

Twelve multiparous Holstein cows (63 ± 24 DIM) were used in a replicated 4×4 Latin square with 28-d periods. Cows were assigned to replications based on milk production with one replication producing more milk (40.3 kg/d) than the other two replications of cows

(32.1 kg/d). Week 1 of each period was used for adjustment to diets, and wk 2 through 4 for data collection. Dietary treatments consisted of either a CC or HOC concentrate mix in combination with a lower forage diet (**LF**) consisting of a 25:25:50 mixture (**LFCC** and **LFHOC**), or a higher forage diet (**HF**) with a 30:30:40 mixture (**HFCC** and **HFHOC**) of corn silage: alfalfa: concentrate mix. High oil corn utilized in this study (Optimum SK104-3, p25) was grown in Northwest Iowa and was genetically unrelated to CC (generic number 2 yellow corn). Diets (Table 1) were formulated to be iso-nitrogenous and to contain more than adequate amounts of major nutrients (NRC, 2001). Cows were housed in a free-stall barn and individually fed a TMR once daily (0700 h) ad libitum using Calan Broadbent feeder doors (American Calan, Inc., Northwood, NH). Amounts fed and refused were recorded daily.

Samples of alfalfa hay, corn silage, and concentrate mixes were collected weekly and stored at -20°C until analyses. Weekly samples were dried at 55°C in a Despatch oven (style V-23; Despatch Oven Co., Minneapolis, MN) for at least 24 h, ground through a 2-mm screen of a Wiley mill (model 3; Arthur H. Thomas Co., Philadelphia, PA), and made into composites by period. Subsamples of feed composites were dried at 105°C for 24 h to correct to 100% DM. Composites were analyzed for CP, ether extract, and ash according to AOAC methods (1997). Samples were reground (Brinkman ultracentrifuge mill, Brinkman Instruments Co., Westbury, NY) through a 1-mm screen before analyses for Ca, P, Mg (AOAC, 1997), and fiber. Neutral detergent fiber (procedure B of Van Soest et al. (1991), ADF (Robertson and Van Soest, 1981), and acid detergent lignin (Lowry et al., 1994) were determined with an ANKOM fiber analyzer using the Filter Bag Technique (ANKOM Technology Corp., Fairport, NY).

Cows were milked twice daily at 0430 and 1600 h, with individual milk weights recorded at each milking. Milk from individual cows was sampled during a 24-h period on the last day of wk 2, 3, and 4 of each period and made into daily composites. Composites were split in two for analyses. One aliquot was refrigerated at 4°C and sent to Valley Queen Cheese Factory (Milbank, SD) for analyses of fat, protein, total solids, and lactose (AOAC, 1997) by mid-infrared spectrophotometry (Multispec; Foss Food Technology Corp., Eden Prairie, MN) and SCC (AOAC, 1997) using a Fossomatic 90 (Foss Food Technology Corp.). Separate aliquots of each week's milk samples were stored at -20°C for butyl ester fatty acid analysis by GLC (Abu-Ghazaleh et al., 2001) with the modification of changing the heating time to 30 min. Esters of fatty acids were separated on a $0.25 \text{ mm} \times 100 \text{ m}$ column (SP2560; Supelco, Inc., Bellefonte, PA). The split ratio in the injector port

Table 1. Ingredient and nutrient content of lower forage conventional corn (LFCC), lower forage high oil corn (LFHOC), higher forage conventional corn (HFCC), and higher forage high oil corn (HFHOC) diets.

Item	50% Forage		60% Forage	
	LFCC	LFHOC	HFCC	HFHOC
	(% of DM)			
Ingredient Composition				
Alfalfa hay	25.00	25.00	30.00	30.00
Corn silage	25.00	25.00	30.00	30.00
Conventional cracked corn	30.80	...	20.90	...
High oil cracked corn	...	30.80	...	20.90
Soybean meal	17.20	17.20	17.10	17.10
High Zn trace mineralized salt	0.25	0.25	0.25	0.25
Magnesium oxide	0.15	0.15	0.15	0.15
Dicalcium phosphate	0.45	0.45	0.40	0.40
Limestone	0.90	0.90	0.90	0.90
Vitamin A, D, & E premix ¹	0.10	0.10	0.10	0.10
Vitamin E premix ²	0.05	0.05	0.05	0.05
Chemical composition				
DM, %	71.2	71.3	68.4	68.4
CP	18.3	18.0	17.1	17.5
RUP ³ , % of CP	33.4	33.4	32.2	32.2
Ether extract	2.97	4.17	3.13	4.22
Total fatty acids	2.73	3.06	2.67	2.99
ADF	21.5	21.4	23.8	23.4
NDF	27.0	27.8	31.0	31.3
Lignin	6.5	6.5	7.0	7.1
NFC ⁴	43.9	43.4	41.8	40.2
Ash	7.8	7.5	7.0	7.5
Ca	0.91	0.98	0.81	0.91
P	0.37	0.43	0.34	0.36
Mg	0.29	0.31	0.28	0.31
NE _L ³ , Mcal/kg	1.65	1.72	1.61	1.65

¹Contains 4,400,000 IU of vitamin A; 880,000 IU of vitamin D, and 440 IU of vitamin E per kg.

²Contains 44,000 IU of vitamin E per kg.

³Estimated from NRC (2001).

⁴NFC = non-fiber carbohydrates, NFC = 100 – (CP+NDF+EE+ash).

(230°C) was 75:1 with a column flow of 1.5 ml/min of He. Oven temperature was programmed to 60°C for 5 min, then increased from 60 to 165°C at 3°C/min, held at 165°C for 10 min, raised to 230°C at 5°C/min, and finally held at 220°C for 32 min. Standard mixtures of fatty acids (FIM-FAME-7; Matreya, Inc., Pleasant Gap, PA; and GLC-68D; Nu Check Prep, Inc., Elysian, MN) and standards of *cis*-9, *trans*-11 and *trans*-10, *cis*-12 conjugated linoleic acid (CLA) (Matreya, Inc., Pleasant Gap, PA) were analyzed for identification of fatty acid composition of milk samples.

Body weights and BCS of cows (Wildman et al., 1982) were recorded at the beginning of the trial and the end of each period. Body weights and BCS were the average of two observations taken at the beginning and end of each period.

Statistical Analysis

Data were analyzed as a replicated 4 × 4 Latin square using the mixed procedures of SAS (1996). Higher producing cows were in one replication, whereas the two

replications of lower producing animals were grouped together for analyses. The statistical model was $Y = \text{forage concentration} + \text{corn type} + \text{rep} + \text{cow (rep)} + \text{wk} + \text{period} + (\text{forage} \times \text{corn}) + (\text{forage} \times \text{rep}) + (\text{corn} \times \text{rep}) + (\text{rep} \times \text{wk})$, where cow (rep) = random effect used to test forage, corn, rep, and interactions of forage × corn, forage × rep, and corn × rep. The residual error was used to test wk and interaction of rep × wk. Forage × wk, corn × wk, forage × corn × rep, forage × corn × week, and forage × corn × rep × wk were tested but were not significant and were not included in the final model. Numerous covariate structures were tested, and the VC (variance components) covariate structure provided the best fit for repeated measurements analysis (SAS, 1996). Data were deleted from one cow for reasons unrelated to the treatments, and statistical analyses were performed with this cow represented as missing data for the entire study. Preplanned contrasts were lower forage diets vs. higher forage diets (F), conventional corn vs. high oil corn (C) and interaction of the two forage concentrations and corn types (F × C). Significance was declared at $P < 0.05$, unless otherwise noted.

Table 2. Fatty acid composition of concentrate mixes, forages, and corn sources from cows fed lower forage conventional corn (LFCC), lower forage high oil corn (LFHOC), higher forage conventional corn (HFCC), and higher forage high oil corn (HFHOC) diets.

Fatty acid ¹	Concentrate mix				Corn silage	Alfalfa hay	Conv. corn	High oil corn
	LFCC	LFHOC	HFCC	HFHOC				
	(g/100 g of fatty acid)							
14:0	0.10	0.40	0.07	nd ²	0.03	0.47	0.04	0.03
14:1	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
16:0	18.59	16.72	17.48	16.05	14.50	34.54	10.97	10.35
16:1	0.11	0.12	0.13	nd ²	0.08	nd ²	0.36	0.08
18:0	4.13	3.91	3.95	3.52	3.12	5.92	1.72	2.16
Total 18:1	30.15	38.54	34.28	39.97	24.22	3.06	24.49	29.23
18:1(t6)	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
18:1(t9)	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
18:1(c6)	2.94	2.18	2.01	2.00	0.54	2.32	nd ²	nd ²
18:1(t11)	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
18:1(c9)	25.33	34.75	30.54	36.55	22.88	0.36	23.83	28.68
18:1(c11)	1.88	1.61	1.73	1.42	0.80	0.38	0.66	0.55
Total 18:2	13.91	10.73	16.24	13.69	41.67	13.81	54.12	41.79
18:2(t9,t12)	nd ²	0.03	nd ²	nd ²	0.04	nd ²	0.03	0.03
18:2(c9,c12)	13.91	10.70	16.24	13.69	41.63	13.81	54.09	41.76
18:3(n-6)	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
20:0	0.45	0.49	0.45	0.48	0.43	1.90	0.36	0.38
18:3(n-3)	0.91	0.71	0.71	0.73	0.89	0.79	1.34	0.88
20:1	0.50	0.59	0.49	0.54	0.27	nd ²	0.20	0.18
22:0	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
20:4	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
20:5(n-3)	nd ²	nd ²	nd ²	nd ²	0.08	nd ²	nd ²	nd ²
22:5	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²
22:6(n-3)	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²	nd ²

¹Expressed as number of carbons:number of double bonds.²nd = Not detectable.

RESULTS AND DISCUSSION

The ingredient and chemical composition of the four diets is shown in Table 1. Crude protein of the HOC and CC was similar (8.6%), but ADF (3.1 vs. 2.0%), NDF (12.0 vs. 7.6), and ether extract (7.0 vs. 4.0) concentrations were greater in the HOC and starch concentration was lower in the HOC (67.5 vs. 71.9). Diets were formulated to be isonitrogenous (18% CP). Crude protein was higher and ADF, NDF, and lignin were lower in LF compared with HF diets. Ether extract and total fatty acid contents were greater in HOC compared with CC diets. The LFCC diet was formulated to contain approximately 1.65 Mcal of NE_L/kg. The diets containing more forage provided a lower energy concentration (1.63 vs. 1.68 Mcal/kg). Diets that contained HOC instead of CC had greater energy concentrations (1.68 vs. 1.63 Mcal/kg). These differences resulted in the energy concentration of the LFCC diet to be similar to that of the HFHOC diet.

Fatty acid composition of concentrate mixes, forages, and corns are presented in Table 2 and for each TMR in Table 3. The concentration of *cis*-9 18:1 was greater and *cis*-9, *cis*-12 18:2, 16:0, and 18:0 were lower in HOC compared with CC diets. Total 18:1 and 18:2 were

greater and 16:0 and 18:0 were lower in HF compared with LF diets.

DMI, Milk Yield, and Milk Composition

The DMI was greater ($P < 0.01$) when cows were fed diets containing lower forage concentrations (28.4 vs. 26.6 kg/d) but was not different ($P > 0.05$) based on corn source (Table 4). The decreased DMI of cows when consuming 60% forage diets is consistent with previous research that showed a negative correlation between forage concentration and intake (Ruiz et al., 1995; West et al., 1998; Khorasani et al., 2001). This was likely a result of the lower overall digestibility of the diets containing more forage (Robinson and McQueen, 1997; Allen, 2000). A week effect was noted for DMI. Intake was similar for wk 2 and 3 but greater ($P < 0.01$) for wk 4 (27.1 vs. 28.2 kg/d).

Dry matter intake responses in trials where dairy cows were fed HOC vs. CC have been variable. Atwell et al. (1988) and LaCount et al. (1995) reported increased DMI when cows were fed HOC vs. CC; however, DM digestibility was decreased in the study by Atwell et al. (1988). The study by LaCount et al. (1995) was a longer term study than the present one, and the results

Table 3. Fatty acid composition of the lower forage conventional corn (LFCC), lower forage high oil corn (LFHOC), higher forage conventional corn (HFCC), and higher forage high oil corn (HFHOC) diets.

Fatty acid ¹	50% Forage		60% Forage	
	LFCC	LFHOC	HFCC	HFHOC
	(g/100 g of fatty acid)			
14:0	0.15	0.31	0.14	0.11
14:1	nd ²	nd ²	nd ²	nd ²
16:0	20.23	19.17	20.03	19.40
16:1	0.08	0.09	0.08	0.03
18:0	4.14	4.02	4.06	3.87
Total 18:1	23.20	28.00	23.62	26.19
18:1(t6)	nd ²	nd ²	nd ²	nd ²
18:1(t9)	nd ²	nd ²	nd ²	nd ²
18:1(c6)	2.11	1.74	1.55	1.55
18:1(t11)	nd ²	nd ²	nd ²	nd ²
18:1(c9)	19.81	25.10	20.96	23.67
18:1(c11)	1.28	1.16	1.10	0.97
Total 18:2	21.85	19.83	24.33	23.13
18:2(t9,t12)	0.01	0.02	0.01	0.01
18:2(c9,c12)	21.84	19.81	24.32	23.12
18:3(n-6)	nd ²	nd ²	nd ²	nd ²
20:0	0.71	0.72	0.76	0.77
18:3(n-3)	0.88	0.77	0.78	0.79
20:1	0.34	0.39	0.30	0.33
22:0	nd ²	nd ²	nd ²	nd ²
20:4	nd ²	nd ²	nd ²	nd ²
20:5(n-3)	0.02	0.02	0.03	0.03
22:5	nd ²	nd ²	nd ²	nd ²
22:6(n-3)	nd ²	nd ²	nd ²	nd ²

¹Expressed as number of carbons:number of double bonds.²nd = Not detectable.

may differ from the present study because changes in production responses to fat supplementation may not be observable in short-term studies (Schingoethe and Casper, 1991). Elliott et al. (1993) found no difference in DMI between HOC and CC, which agreed with the results of the present study.

Body weights of cows when fed the diets containing 50% forage were greater ($P = 0.03$) and BCS tended to be higher ($P = 0.06$) than when fed the 60% forage diets (652 vs. 643 kg and 2.78 vs. 2.72 for BW and BCS, respectively). Cows fed the lower forage diets gained an average of 19.4 kg per period, whereas cows fed the higher forage diets only gained an average of 5.5 kg per period. The periods were only 4 wk in length; BW and BCS changes over these short time periods are not entirely reliable. Khorasani et al. (2001) also reported a tendency for cows to be heavier when fed a 50 vs. a 35% concentrate diet.

Milk production was greater ($P = 0.03$) when cows were fed the diets with lower forage concentration (37.0 vs. 35.4 kg/d), but was not different ($P > 0.05$) based on corn source. Studies conducted by Atwell et al. (1988) and Elliott et al. (1993) showed no difference in milk production between cows fed CC or HOC. Chouinard et al. (2001), however, reported an increase in milk production from cows that were fed HOC compared with

CC. Additionally, Weiss and Wyatt (2000) showed an increase in milk production that tended ($P < 0.09$) to be higher from cows fed HOC silage compared to CC silage. In a longer study by LaCount et al. (1995), cows fed HOC tended ($P < 0.07$) to have increased milk production in wk 4 through 17 of lactation as compared with cows fed CC.

Milk production commonly decreases when forage or dietary NDF concentration increases in the diet, as observed in the present study. Ruiz et al. (1995) reported milk production decreased from 23.0 to 21.7 kg/d when diet NDF concentration increased from 31 to 39%. In the current study, NDF concentrations were lower than those reported by Ruiz et al. (1995) and increased by only three to four units from the lower dietary forage to higher dietary forage concentrations. Milk production and intake were much higher, however, in the current study, and the cows may have been more sensitive to a slowed passage rate resulting from changes in nutrient digestibility. An increased sensitivity to changes in nutrient digestibility could lead to differences in production with less difference in diet composition. In contrast to milk production, energy-corrected milk and FCM were similar for both forage ratios, as a result of the higher ($P < 0.05$) concentration of fat in the milk of cows fed the higher forage diets.

Table 4. Dry matter intake, milk yield, milk composition, milk SCC, BW, and BCS when cows were fed the lower forage conventional corn (LFCC), lower forage high oil corn (LFHOC), higher forage conventional corn (HFCC), and higher forage high oil corn (HFHOC) diets.

	50% Forage		60% Forage		SE	Effects ¹		
	LFCC	LFHOC	HFCC	HFHOC		F	C	F*C
							(P)	
DMI, kg/d ²	28.1	28.7	26.9	26.2	0.9	<0.01	0.90	0.25
Milk, kg/d ³	36.8	37.2	35.5	35.2	1.5	0.03	0.94	0.65
ECM ⁴ , kg/d	38.2	37.8	36.7	37.0	1.9	0.10	0.95	0.64
3.5% FCM ⁵ , kg/d	38.3	37.7	37.0	37.2	1.9	0.19	0.76	0.57
Milk fat								
%	3.98	3.79	3.99	4.07	0.14	0.04	0.41	0.04
kg/d	1.41	1.36	1.37	1.38	0.07	0.72	0.51	0.26
Milk protein								
% ²	3.24	3.22	3.17	3.23	0.07	0.23	0.38	0.15
kg/d	1.15	1.16	1.08	1.10	0.06	0.03	0.60	0.98
Milk lactose								
%	4.79	4.81	4.81	4.74	0.06	0.33	0.33	0.14
kg/d ³	1.76	1.80	1.71	1.68	0.08	0.04	0.95	0.37
Milk total solids								
% ⁶	12.66	12.47	12.64	12.72	0.20	0.05	0.34	0.02
kg/d ³	4.64	4.64	4.46	4.46	0.20	0.05	0.96	0.97
Milk SCC × 10 ³ /ml ⁷	356	286	223	327	164	0.56	0.83	0.27
BW, kg	655	649	642	644	24	0.03	0.65	0.30
BCS ⁸	2.81	2.75	2.69	2.74	0.07	0.06	0.94	0.16

¹F = Diets containing 50 percent forage vs diets containing 60 percent forage (LFCC and LFHOC vs HFCC and HFHOC), C = diets containing conventional corn vs diets containing high oil corn (LFCC and HFCC vs LFHOC and HFHOC), F*C = Interaction of forage level and corn type.

²Effect of week ($P < 0.05$).

³Effect of rep ($P < 0.05$).

⁴ECM = energy-corrected milk (Orth, 1992).

⁵FCM (Parekh, 1986).

⁶Interaction of forage*rep ($P < 0.05$).

⁷Interaction of corn*rep ($P < 0.05$).

⁸BCS, 1 = emaciated and 5 = overly fat (Wildman et al., 1982).

Milk fat concentration was higher ($P < 0.05$) when cows were fed the higher forage diets (4.03 vs. 3.88%). Additionally, a forage concentration × corn source interaction ($P < 0.05$) was observed for milk fat concentration. For cows when fed the two diets containing 50% forage, milk fat concentration was higher ($P < 0.05$) for CC, whereas milk fat concentration was numerically higher ($P > 0.38$) from HOC when fed the 60% forage diets. Milk fat concentration was not affected by corn source. This observation is consistent with the findings of Atwell et al. (1988), Elliott et al. (1993), and Weiss and Wyatt (2000), who did not find any difference in milk fat concentration or yields, and with Chouinard et al. (2001), who reported no differences in milk fat concentration. LaCount et al. (1995) observed a 0.2-unit increase in milk fat concentration, however, when cows were fed a CC silage and HOC grain diet compared with a CC silage and CC grain diet. Milk fat yields in the current study were not different ($P > 0.05$) based on forage concentrations or corn types.

Milk protein concentration was not different ($P > 0.05$) based on forage concentrations or corn types.

Studies by Atwell et al. (1988) and Elliott et al. (1993) also showed no differences in protein concentration or yield when cows were fed either CC or HOC. This is in contrast to Weiss and Wyatt (2000), who observed a decrease in milk protein concentration when cows were fed HOC silage compared with CC silage. The study conducted by Weiss and Wyatt (2000) utilized HOC diets containing greater concentrations of fatty acids than the present study and would more likely decrease protein concentration (Casper and Schingoethe, 1989). Cows fed the diets containing 50% forage in the current study produced more ($P < 0.04$) milk protein than cows fed the diets containing 60% forage (1.16 vs. 1.09 kg/d). This increase in protein yield is primarily a reflection of the greater milk production of cows fed the lower concentration of forage. A week effect was noted for milk protein concentration. Milk protein concentration increased ($P < 0.01$) from wk 2 through wk 4 (3.16, 3.22, and 3.27 % for wk 2, 3, and 4, respectively).

Milk lactose, and total solids produced were greater ($P < 0.05$) in cows that were in the higher as compared with the lower production rep. An interaction of forage

× rep was observed for total solids concentration. Total solids concentration was greater for cows in rep 1 when they were fed the 60% forage diet (12.53 vs. 12.25%), but total solids concentration was similar for cows in rep 2 at both forage concentrations (12.84 and 12.87% for cows fed 60 and 50% forage, respectively).

Fatty Acid Composition of Milk

The concentration of short-chain fatty acids (4:0 to 12:0) in milk was not affected by forage concentration or corn source (Table 5). However, the concentration of medium-chain fatty acids (14:0 to 16:1) decreased ($P < 0.01$) and the concentration of long-chain fatty acids (17:0 to 22:6) increased ($P < 0.01$) when cows were fed HOC compared with CC (47.60 vs. 49.94 and 31.88 vs. 29.22 g/100 g of fatty acids for medium- and long-chain fatty acids on the HOC and CC diets, respectively). The increase in long-chain fatty acids was expected and is consistent with other studies in which additional fat (Palmquist and Jenkins, 1980), including HOC (Atwell et al., 1988; Elliott et al., 1993; Chouinard et al., 2001) was fed.

Unsaturated fatty acids increased ($P < 0.01$) and saturated fatty acids decreased ($P < 0.03$) when cows were fed the HOC diets compared with the CC diets (26.78 vs. 25.26 and 66.80 vs. 68.24 g/100 g of fatty acids for unsaturated and saturated fatty acids on the HOC and CC diets, respectively). An increase in unsaturated fatty acids occurred in meat samples from cattle fed HOC (Andrae et al., 2001). No difference in the saturation of fatty acids due to proportion of forage fed was observed in the present study, but Kucuk et al. (2001) noted increased biohydrogenation in ewes fed increasing concentrations of forage.

Vaccenic acid (*trans*-11 18:1, **TVA**) and two CLA isomers (*cis*-9, *trans*-11 18:2 and *trans*-10, *cis*-12 18:2) were identified in this trial because of their reported health benefits and likely role in milk fat depression. Health benefits, such as antiatherosclerotic, anticarcinogenic, and antiobesity properties, associated with the consumption of *cis*-9, *trans*-11 CLA have been reported (Lee et al., 1994; Ip et al., 1999; West et al., 2000). The human body is capable of converting TVA into *cis*-9, *trans*-11 CLA (Salminen, et al., 1998); thus, consumption of TVA is likely to give similar health benefits to humans as consumption of *cis*-9, *trans*-11 CLA. The *trans*-10, *cis*-12 isomer of CLA (Baumgard et al., 2001), along with other *trans*-10 C18 fatty acids [e.g., *trans*-10 18:1, Griinari et al. (1998)] appear to be associated with a decreased milk fat concentration. A forage × corn source interaction was observed for milk TVA concentration. The concentration of milk TVA was similar when cows were fed either forage ratio with the CC.

Cows produced more ($P < 0.02$) TVA when fed the LFHOC diet compared with the HFHOC diet, resulting in the forage concentration × corn source interaction. The greater production of TVA at lower forage levels and fat supplementation is supported by Kucuk et al. (2001). These authors reported a decrease in duodenal flow of TVA as dietary forage concentration increased up to 72.9% of the diet. Similarly, the *cis*-9, *trans*-11 CLA isomer showed a forage concentration × corn source interaction caused by similar CLA concentrations on the CC diets at both forage concentrations but a greater concentration of CLA on the LFHOC diet and not on the HFHOC diet. A slight increase in CLA when cows were fed HOC compared with CC has also been reported (Chouinard et al., 2001). Kucuk et al. (2001) did not observe any difference in duodenal flow of *cis*-9, *trans*-11 CLA when ewes were fed forage concentrations similar to those fed in the present study. The concentration of the *trans*-10, *cis*-12 CLA isomer was not affected by forage concentration or corn source. Both CLA isomers changed from wk 2 through wk 4. The *cis*-9, *trans*-11 CLA isomer concentration decreased ($P < 0.05$) each week (0.36, 0.33, and 0.31 g/100 g of fatty acids for wk 2, 3, and 4, respectively), while the *trans*-10, *cis*-12 CLA isomer concentration was similar in wk 2 and 3, but higher ($P < 0.01$) in wk 4 (0.003, 0.005, and 0.027 g/100 g of fatty acids for wk 2, 3, and 4, respectively).

Total identified 18:1 fatty acid concentrations were greater ($P < 0.01$) in milk when cows were fed HOC compared with CC (19.42 vs. 17.87 g/100 g of fatty acids) but were not different between forage concentrations. Research has shown an increase in total 18:1 fatty acids when cows were fed HOC vs. CC (Elliott et al., 1993; LaCount et al., 1995; Chouinard et al., 2001) with the exception of one trial, where no difference in 18:1 fatty acids was observed (Atwell et al., 1988). The *trans*-6 18:1, *trans*-9 18:1, and *cis*-6 18:1 isomers were all present in greater concentrations in the 50% forage diets ($P < 0.01$) and in the HOC diets ($P < 0.01$). This increase was greater from the CC to HOC diet in the 50% than in the 60% forage diets, leading to a forage concentration × corn source interaction. Oleic acid (*cis*-9 18:1) was also present in greater ($P < 0.02$) quantities in milk when cows were fed the HOC diets (17.20 vs. 16.02 g/100 g of fatty acids) compared with milk when cows were fed the CC diets, but there was no forage effect. The *cis*-11 18:1 isomer did not differ based on corn source, but was greater ($P < 0.01$) in milk when cows were fed the 50% forage diets (0.63 vs. 0.56 g/100 g of fatty acids). The *cis*-11 18:1 isomer concentration was lower ($P < 0.05$) in wk 3 than in wk 2 and 4 (0.55 vs. 0.64 and 0.59 g/100 g of fatty acids for wk 3, 2, and 4, respectively). Both the *cis*-6 and *cis*-11 isomers of 18:1 showed significant forage × rep interactions. Both fatty acids concen-

Table 5. Fatty acid composition of milk fat when cows were fed lower forage conventional corn (LFCC), lower forage high oil corn (LFHOC), higher forage conventional corn (HFCC), and higher forage high oil corn (HFHOC) diets.

Fatty acid ²	50% Forage		60% Forage		SE	Effects ¹		
	LFCC	LFHOC	HFCC	HFHOC		F	C	F*C
	(g/100 g of fatty acid)					(P)		
4:0 ³	3.17	3.20	3.29	3.30	0.08	<0.01	0.55	0.87
6:0 ⁴	2.13	2.12	2.18	2.21	0.05	0.01	0.74	0.43
8:0 ³	1.36	1.34	1.35	1.35	0.04	0.94	0.60	0.60
10:0 ³	3.47	3.41	3.37	3.32	0.15	0.04	0.19	0.96
12:0 ³	4.35	4.16	4.13	4.00	0.21	<0.01	0.02	0.69
14:0 ³	12.19	11.97	11.95	11.90	0.32	0.28	0.36	0.56
14:1 ^{3,5}	1.62	1.51	1.56	1.53	0.10	0.55	0.02	0.14
15:0	1.41	1.24	1.28	1.24	0.06	0.04	<0.01	0.04
16:0 ³	32.75	30.06	32.79	31.64	0.95	0.12	<0.01	0.14
16:1	2.18	1.98	2.15	2.04	0.09	0.62	<0.01	0.13
17:0 ³	0.58	0.53	0.58	0.55	0.01	0.17	<0.01	0.59
18:0	7.01	8.02	7.30	8.06	0.37	0.45	<0.01	0.57
Total 18:1	17.69	20.00	18.05	18.84	0.80	0.42	<0.01	0.13
18:1(t6)	0.12	0.21	0.12	0.17	<0.01	<0.01	<0.01	<0.01
18:1(t9)	0.16	0.23	0.15	0.19	<0.01	<0.01	<0.01	<0.01
18:1(c6) ⁴	0.38	0.53	0.36	0.44	0.04	<0.01	<0.01	0.03
18:1(t11)	0.58	0.81	0.62	0.69	0.04	0.21	<0.01	0.02
18:1(c9)	15.83	17.60	16.20	16.79	0.73	0.63	0.01	0.20
18:1(c11) ^{3,4}	0.63	0.63	0.56	0.55	0.05	<0.01	0.85	0.70
18:2(t9,t12) ^{3,4}	0.20	0.25	0.18	0.21	0.02	<0.01	<0.01	0.04
18:2(c9,c12) ⁴	2.33	2.67	2.22	2.24	0.09	<0.01	<0.01	<0.01
Total CLA	0.30	0.41	0.33	0.35	0.02	0.53	<0.01	0.01
18:2(c9,t11) ³	0.28	0.39	0.32	0.33	0.02	0.53	<0.01	0.01
18:2(t10,c12) ³	0.01	0.01	0.01	0.01	<0.01	0.86	0.47	0.34
18:3(n-6)	0.11	0.11	0.12	0.12	<0.01	0.08	0.70	0.86
18:3(n-3) ³	0.50	0.46	0.52	0.51	0.03	0.10	0.37	0.58
20:1 ³	0.13	0.11	0.12	0.12	0.01	0.88	0.31	0.25
20:5(n-3) ³	0.05	0.05	0.05	0.06	<0.01	0.22	0.39	0.53
22:5 ³	0.06	0.06	0.07	0.05	<0.01	0.67	0.21	0.06
22:6(n-3)	nd ⁶	nd ⁶	nd ⁶	nd ⁶				
Unidentified ³	6.48	6.55	6.60	6.44	0.22	0.98	0.83	0.52
Total n-3 FA ^{3,7}	0.55	0.52	0.59	0.56	0.03	0.12	0.24	0.88
Short ^{3,8}	14.48	14.23	14.30	14.16	0.40	0.38	0.19	0.69
Medium ^{3,9}	50.17	46.77	49.71	48.42	1.00	0.38	<0.01	0.12
Long ¹⁰	28.89	32.61	29.54	31.15	1.02	0.57	<0.01	0.14
Unsaturated	25.16	27.58	25.37	25.98	0.92	0.19	<0.01	0.09
Saturated ³	68.39	65.97	68.10	67.63	1.06	0.28	0.02	0.12

¹F = Diets containing 50 percent forage vs diets containing 60 percent forage (LFCC and LFHOC vs HFCC and HFHOC), C = diets containing conventional corn vs diets containing high oil corn (LFCC and HFCC vs LFHOC and HFHOC), F*C = Interaction of forage level and corn type.

²Expressed as number of carbons:number of double bonds.

³Effect of week ($P < 0.05$).

⁴Interaction of forage*rep ($P < 0.05$).

⁵Interaction of week*rep ($P < 0.05$).

⁶nd = Not detectable.

⁷n-3 fatty acids: 18:3(n-3), 20:5(n-3), 22:6(n-3).

⁸Short-chain fatty acids: (4:0 to 12:0).

⁹Medium-chain fatty acids: (14:0 to 16:1).

¹⁰Long-chain fatty acids: (17:0 to 22:6).

trations were lower ($P < 0.01$) on the 60% forage diet for cows in the higher producing rep (0.39 vs. 0.48 and 0.54 vs. 0.66 g/100 g of fatty acids for the *cis*-6 and *cis*-11 isomers on the 60 and 50% forage diets, respectively). Concentrations of *cis*-6 and *cis*-11 18:1 were similar ($P > 0.54$) between forage concentrations for the lower producing rep (0.41 vs. 0.43 and 0.58 vs. 0.60 g/100 g

of fatty acids for the *cis*-6 and *cis*-11 isomers on the 60 and 50% forage diets, respectively).

Forage concentration or corn source did not affect total n-3 fatty acid concentrations in milk. Only α -linolenic acid (18:3 n-3) and eicosapentaenoic acid (20:5 n-3) were detected in these samples. Forage concentration or corn source affected neither individual fatty acid.

The n-3 fatty acids were affected by sample wk, decreasing from wk 2 to 4. The concentration of α -linolenic acid was greater ($P < 0.01$) in wk 2 and similar ($P > 0.22$) in wk 3 and 4 (0.59, 0.47, and 0.43 g/100 g of fatty acids for wk 2, 3, and 4, respectively). The concentration of eicosapentaenoic acid was greater ($P < 0.01$) in wk 2 than 4, and tended ($P < 0.07$) to be greater in wk 2 than in wk 3, but was not different ($P > 0.35$) between wk 3 and 4 (0.07, 0.04, and 0.05 g/100 g of fatty acids for wk 2, 3, and 4, respectively). Thus, total n-3 fatty acids were greater ($P < 0.01$) in wk 2 than wk 3 and 4, and similar ($P > 0.25$) in wk 3 and 4 (0.63, 0.53, and 0.50 g/100 g of fatty acids for wk 2, 3, and 4, respectively).

CONCLUSIONS

The lower forage concentration fed in this study increased DMI and milk production and decreased milk fat concentration, while corn source had no effect on any of the production parameters. In contrast, high oil corn increased unsaturation of milk fatty acid, chain length, TVA, CLA, and total 18:1 concentrations. Diet forage concentration had little effect on most milk fatty acid concentrations. Differences in oil concentrations in this study may not have given enough of an energy increase to the high oil corn diets to determine overall differences related to high oil corn addition in diets with different forage: concentrate ratios.

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