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Effect of Type and Level of Dietary Fat on Rumen Fermentation and Performance of Dairy Cows Fed Corn Silage-Based Diets

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ABSTRACT

The objective of this study was to investigate the effects of tallow and choice white grease (CWG) fed at 0, 2, and 4% of the diet dry matter (DM) on rumen fermentation and performance of dairy cows when corn silage is the sole forage source. Fifteen midlactation Holstein cows were used in a replicated 5 × 5 Latin square design with 21-d periods. Treatments were 0% fat (control), 2% tallow, 2% CWG, 4% tallow, and 4% CWG (DM basis). The forage:concentrate ratio was 50:50, and diets were formulated to contain 18% crude protein and 32% neutral detergent fiber (DM basis). Cows were allowed ad libitum consumption of diets fed twice daily as total mixed rations. Cows fed supplemental fat had lower DM intake and produced less milk and milk fat than cows fed the control diet. Feeding 4% fat reduced milk production and milk fat yield relative to feeding 2% fat. Treatments had little effect on the concentration of *trans*-octadecenoic acids in milk fat. Total *trans* fatty acids were poorly related to changes in milk fat percentage. Ruminal pH and total volatile fatty acids concentration were not affected by supplemental fat. The acetate:propionate ratio, NH_3-N, and numbers of protozoa in the rumen were significantly decreased when fat was added to the diets. Source of dietary fat did not affect rumen parameters. There was no treatment effect on in situ corn silage DM and neutral detergent fiber disappearance. Including fat in corn silage-based diets had negative effects on milk production and rumen fermentation regardless of the source or level of supplemental fat.
(**Key words:** type and level of fat, rumen fermentation, milk fat, corn silage)

Abbreviation key: A:P = ruminal acetate to propionate ratio, **CLA** = conjugated linoleic acid, **CWG** = choice white grease, **FA** = fatty acid, **MFD** = milk fat depression, **UFA** = unsaturated fatty acids.

INTRODUCTION

Tallow and choice white grease (**CWG**) are animal fats commonly used in dairy diets (Shaver, 1990). Because rendered fats are a relatively inexpensive source of fat, there is great interest in maximizing their utilization by dairy cows. The response of lactating dairy cows to rendered fats has not been consistent (Smith and Harris, 1993). Differential responses may be attributed to the level of dietary fat, fatty acid (**FA**) profile of the fat source, or interactions between fat source and feed ingredients of the basal diet. For supplemental fat to be beneficial, it must not compromise rumen fermentation and, concomitantly, DMI and milk fat percentage.

Evidence suggests that negative responses to fat may be more likely to occur when corn silage is the major forage source. Smith and Harris (1993) compiled data from lactation trials in which various fat sources were fed with corn silage-, alfalfa-, or corn silage/alfalfa-based diets. They concluded that the likelihood of decreased milk and(or) milk fat percentage was higher when rendered animal fats were fed with corn silage-based diets compared with alfalfa-based diets.

Tallow and CWG differ in the ratio of unsaturated to saturated fatty acids. Feeding tallow often does not cause negative effects due to its adequate ruminal inertness (Shaver, 1990). Unsaturated fatty acids (**UFA**) are toxic for rumen microbes and decrease fiber digestion (Palmquist and Jenkins, 1980; Pantoja et al., 1994). To our knowledge, a direct comparison of increasing levels of tallow and CWG supplementation to dairy diets has not been conducted. Moreover, little information is available on the effects of feeding CWG to lactating dairy cattle. The objective of this study was to investigate the effects of tallow and CWG fed at 0, 2, and 4% of the diet DM on rumen fermentation and performance of dairy cows when corn silage is the

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Table 1. Ingredient composition of experimental diets.

Ingredient	Control	2% Tallow	2% CWG[1]	4% Tallow	4% CWG
	(% DM)				
Corn silage	50	50	50	50	50
Blood meal	1	1	1	1	1
Meat and bone meal	3	3	3	3	3
Distillers grain	5	5.25	5.25	5	5
Soybean meal	13.6	15.6	15.6	17.6	17.6
Cracked corn	12	10.5	10.5	9	9
Soybean hulls	13.25	10.5	10.5	8.25	8.25
Urea	0.4	0.4	0.4	0.4	0.4
Limestone	0.9	0.9	0.9	0.9	0.9
Magnesium oxide	0.05	0.05	0.05	0.05	0.05
Mineral-vitamin mix[2]	0.8	0.8	0.8	0.8	0.8
Fat	. . .	2	2	4	4

[1]CWG = Choice white grease.

[2]Contained 0.55% Mn, 0.55% Zn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, and 0.002% Co, and 3304 IU of vitamin A/g of DM, 1101 IU of vitamin D/g of DM, and 11 IU of vitamin E/g DM.

sole forage source. We hypothesized that CWG would be more likely than tallow to have negative effects because its fatty acid profile is more unsaturated.

MATERIALS AND METHODS

Animals

Fifteen Holstein cows averaging 117 ± 11 DIM and 672 ± 90 kg of BW were used in a replicated 5 × 5 Latin square design with 21-d periods. One square consisted of primiparous cows, one of multiparous cows without rumen cannulas, and one of multiparous cows with rumen cannulas. Cows within a square were assigned randomly to dietary treatments. Treatment sequences were ordered to minimize residual or carryover effects of any treatment in the succeeding period. Animals were handled according to the recommendations and procedures approved by the Research Animal Resources Center of the UW-Madison (RARC # A-00898-3-10-98). Cows were housed individually in a tie-stall and stanchion barn and had free-choice access to water. All cows were injected with bST (Posilac, Monsanto Company, St. Louis, MO) on the same day every 14 d.

Diets

Ingredient composition of the experimental diets is shown in Table 1. Experimental diets consisted of 50% concentrate and 50% processed corn silage (DM basis). The corn hybrid used was Pioneer 3563 (Pioneer Hi-Bred International, Des Moines, IA) harvested at a theoretical length of chop of 12 mm. Fat treatments (DM basis) were: 1) control (no added fat); 2) 2% tallow; 3) 2% CWG; 4) 4% tallow; and 5) 4% CWG. Fat was incorporated into concentrates and then added to TMR. Fatty acid composition of tallow (Packerland Packing Co., Inc., Green Bay, WI) and CWG (Rochelle Food Corp., Rochelle, IL) is shown in Table 2. Cows were fed the diets twice daily (0800 and 1800 h) as a TMR to allow ad libitum consumption. The amount of TMR offered and refused was monitored daily, and refusals were maintained at approximately 10% (as-fed basis). Diets were formulated to be isonitrogenous, and to meet or exceed the NRC (1989) nutrient allowances.

Sampling and Laboratory Analysis

Dry matter contents of corn silage and concentrates were determined weekly using a 60°C forced-air oven; results were used to adjust as-fed ratios in the TMR. The TMR amount offered and refused was measured daily. Orts were collected on d 17 to 21 of each period and dried overnight in a 100°C forced-air oven for DMI determination. Corn silage and concentrate samples

Table 2. Fatty acid composition (g of fatty acid/g of DM) of fat sources.

Fatty acid	Tallow	CWG[1]
$C_{14:0}$	2.8	1.4
$C_{16:0}$	24.8	23.8
$C_{16:1}$	2.6	3.0
$C_{18:0}$	19.8	10.9
$C_{18:1}$	42.7	47.6
$C_{18:2}$	3.3	11.7
$C_{18:3}$	0.4	0.5
$C_{20:0}$	0.4	0.1
Other	3.2	1.0
U/S[2]	0.8	1.3

[1]CWG = Choice white grease.

[2]U/S = Unsaturated:saturated ratio.

were collected weekly, dried 48 h in a 60°C forced-air oven, and ground to pass a 2-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Samples were analyzed for DM, OM, NDF (Mertens, 1999), CP (AOAC, 1990), ether extract (AgSource, Bonduel, WI), and fatty acid (Sukhija and Palmquist, 1988). The nonfibrous carbohydrate component was calculated as 100 – (NDF + ether extract + CP + ash).

Cows were milked twice daily, and milk production was recorded at each milking during the final 7 d of each period. Milk samples from the a.m. and p.m. milking were collected on five consecutive days (d 17 to 21 of each period) and were analyzed for fat, CP, and SNF by infrared analysis (AgSource Milk Analysis Laboratory, Menomonie, WI). Milk samples from d 18 and 19 were composited for fatty acid analysis (Griinari et al., 1998).

For rumen sample collection, cows were fed the total amount of feed once daily (0800 h). Rumen fluid was sampled from cannulated cows before feeding (0 h) and at 2, 4, 6, 8, 10, and 12 h after feeding on d 20. Samples were taken from five different locations in the rumen with a metal filter probe. From noncannulated cows, samples were taken at 4 h after feeding by rumenocentesis (Nordlund and Garrett, 1994). Rumen pH was determined immediately after the samples were collected (Twin pH-meter model B-213, Spectrum Technologies Inc., Plainfield, IL). One milliliter of rumen fluid was acidified with 20 μl of 50% H_2SO_4 and frozen until analysis for VFA as described by Bal et al. (2000), and 1 ml was mixed with 20 μl of 50% TCA and frozen until analysis for NH_3-N (Chaney and Marbach, 1962). Total protozoa numbers in rumen contents were determined as described by Dehority (1984). Briefly, 10 ml of strained rumen fluid were taken from cannulated cows and mixed with 10 ml of 50% formalin (18.5% formaldehyde). Two drops of brilliant green dye were added to 1-ml aliquots and allowed to stand overnight. After staining, 9 ml of 30% glycerol solution were added, and the diluted samples were pipetted into a Sedgewick-Rafter counting chamber (1-cm^3 volume). Further dilutions were made with 30% glycerol when needed. Protozoa were counted at a magnification of 100×.

On d 18 and 19 of each period, 25- × 35-cm Dacron polyester bags (52 ± 5 μm pore size, R102 Marvelaire White, N. Erlanger, Blumgardt and Co., Inc. New York, NY) were incubated in triplicate in the rumen for 12, 24, and 48 h to determine in situ DM and NDF disappearance. Bags containing fresh, unground corn silage (23 ± 1.3 g of DM) without drying or grinding were placed in a nylon laundry bag in the ventral sac of the rumen. After incubation, bags were washed in a commercial washing machine with cold water for three cycles of 15 min each (Cherney et al., 1990). The in situ bags were dried at 60°C in a forced-air oven for 48 h to determine DM disappearance. Residues from triplicate bags were then composited and analyzed for NDF.

Statistics

All data were analyzed using the mixed procedure of SAS (SAS User's Guide, 1998). Single degree of freedom orthogonal comparisons were used to test for the effect of fat, fat source (tallow vs. CWG), level (2% vs. 4%), and source × level interaction.

For DMI, milk yield and composition data, and rumen measurements at 4 h after feeding, the full model included the effects of square, period, treatment, square × period, square × treatment, and period × treatment. Cow within square was the specified term for the random statement. Interaction terms that were not significant ($P > 0.25$) were removed from the model. Period × treatment interactions were not significant ($P > 0.25$) for any of the above-mentioned variables.

Ruminal pH, NH_3-N, VFA, and total protozoa counts from cannulated cows, and in situ DM and NDF degradability were analyzed by time as repeated measures. The model included period, treatment, time, and treatment × time interaction. The terms specified for the random statement were cow and cow × period × treatment. The covariance structure used to fit the model was selected based on the Akaike's information criterion of the mixed models of SAS.

Least squares means are reported throughout. In all cases, significance was declared at $P < 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Diet Composition

Chemical composition of experimental diets is presented in Table 3. Crude protein content was similar across diets and was one percentage unit lower than as formulated, averaging 16.9%. Compared with the control diet, NDF was 4 and 7 percentage units lower for the 2 and 4% fat treatment, respectively, probably because of the lower inclusion of soybean hull NDF with each increase in added fat. Ether extract and FA content increased with fat supplementation. The FA content of both 2% supplemental fat treatments was 0.5 to 0.6 percentage units lower, and that of the 4% CWG treatment was 1.2 percentage units lower than expected. This was likely because fat stuck to the grinder walls as was observed while processing the samples or fat stuck to the mixer walls during TMR preparation (Drackley et al., 1994). Dietary NE_L in-

Table 3. Chemical composition of experimental diets.[1]

	Control	2% Tallow	2% CWG[2]	4% Tallow	4% CWG
DM, %	51.3	51.4	51.3	51.4	51.4
NE_L (Mcal/kg DM)[3]	1.70	1.77	1.77	1.86	1.86
			(% of DM)		
CP	16.7	16.6	17.2	17.0	17.0
NDF	34.0	30.6	29.3	27.5	27.0
NFC[4]	41.6	42.8	43.7	43.3	44.1
EE[5]	2.9	5.1	4.9	7.2	6.9
Fatty acid	3.0	4.3	4.4	6.9	5.6

[1]Diets contained 0.9% Ca, 0.47% P, and 0.26% Mg.
[2]CWG = Choice white grease.
[3]Calculated using NRC values (NRC, 1989).
[4]NFC = Nonfibrous carbohydrates = 100 − (NDF + CP + EE + ash).
[5]EE = Ether extract.

creased by an average of 0.08 Mcal/kg of DM with each increase in fat supplementation.

Lactation Performance

Least square means for DMI, milk production, and milk composition are shown in Table 4. Cows fed supplemental fat consumed 2 kg/d less DM than control cows. There was a trend ($P < 0.08$) for lower DMI of cows receiving 4% supplemental fat than 2% supplemental fat. The decrease in DMI had no effect on the calculated NE_L intake (Table 4) due to the higher energy concentration of the diets containing supplemental fat. The decrease in DMI observed in this study when supplemental fat was fed could also reflect the lower NDF content of diets containing fat. Dry matter intake responses to supplemental fats have been inconsistent. In a recent summary of the literature, Allen (2000) evaluated linear and quadratic effects of added FA from different fat sources on DMI; he observed negative linear effects for unprocessed animal fats. However, feeding 3 to 5% tallow with alfalfa/corn silage-based diets had no effect on DMI (Grummer et al., 1993; Drackley et al., 1994; Weigel et al., 1997; Jenkins et al., 1998). Smith et al. (1993) observed no effect of tallow on DMI for cows fed corn silage-based diets or diets in which alfalfa hay replaced a portion of the corn silage. Contrary to the results in our study, in which no significant effect of dietary fat source was found, Pantoja et al. (1994) observed a linear decrease in DMI as degree of unsaturation increased. Feeding 6% of dietary DM as CWG with corn silage-based diets decreased DMI 2.5 kg/d (Tackett et al., 1996), but the difference was not statistically significant.

Milk production was decreased ($P < 0.01$) with fat supplementation and was most pronounced for cows receiving 4% fat in the diet (42.3, 41.1, and 38.1 kg/d for control, 2% fat, and 4% fat, respectively). There was no effect of fat source on milk yield. The same response was observed for 4% FCM yield (Table 4).

Table 4. Least square means for DMI and milk production and composition.

	Treatments						Statistical contrasts ($P <$)			
	Control	2% Tallow	2% CWG[1]	4% Tallow	4% CWG	SE	Control vs. Fat	Source	Level	Source × Level
DMI, kg/d	26.3	24.8	24.4	23.7	23.8	0.7	0.01	NS[2]	0.08	NS
NE_LI,[3] Mcal/d	44.7	43.9	44.2	44.1	44.3	1.3	NS	NS	NS	NS
Milk, kg/d	42.3	40.7	41.5	38.1	38.1	2.5	0.01	NS	0.01	NS
4% FCM, kg/d	37.8	33.4	34.6	32.1	31.4	1.9	0.01	NS	0.01	NS
Fat, %	3.30	2.83	2.93	3.00	2.85	0.12	0.01	NS	NS	0.01
Fat, kg/d	1.39	1.14	1.21	1.12	1.08	0.07	0.01	NS	0.03	0.01
Protein, %	3.23	3.30	3.27	3.32	3.34	0.07	0.01	NS	0.06	NS
Protein, kg/d	1.35	1.33	1.33	1.25	1.26	0.07	0.06	NS	0.01	NS
SNF, %	8.79	8.88	8.85	8.85	8.90	0.09	0.04	NS	NS	NS

[1]CWG = Choice white grease.
[2]NS = Nonsignificant.
[3]NE_LI = NE_L Intake.

Decreased milk production for fat supplemented cows was probably due to their lower DMI. Although DMI was not different between cows fed 2 or 4% supplemental fat, including 4% fat in the diets had a more negative impact on rumen fermentation than including 2% fat. This may have led to lower energy availability for milk production. Milk yield responses to supplemental tallow have been variable. Some studies report increased milk production when supplemental tallow is fed (Drackley et al. 1994; Jenkins et al., 1998), while others show no response (Grummer et al., 1993; Weigel et al., 1997). Because these studies were all conducted on early-lactation cows, the variable responses may be a consequence of differences in the nutrient composition of the basal diets or differences in the fatty acid profile of the supplemental tallow. Adding 6% CWG to corn silage-based diets did not affect milk yield (Tackett et al., 1996). Pantoja et al. (1994) showed no effect of degree of fat unsaturation on milk production.

Cows consuming fat-supplemented diets produced less milk fat than cows fed the control diet ($P < 0.01$) as a result of lower milk yield and reduced milk fat concentration ($P < 0.01$). Milk fat percentage depression is observed under several dietary manipulations, including low fiber diets, supplementation with fats that are active in the rumen, or a combination of both (Gaynor et al., 1995; Griinari et al., 1998). Our results suggest that tallow, although more saturated than CWG, has an adverse effect on rumen fermentation and milk fat test when corn silage is the sole forage source. Tallow tended to decrease milk fat percentage when included in diets with corn silage as the sole forage source (Smith et al., 1993). Tackett et al. (1996) observed a 0.5 percentage unit decrease in milk fat test when CWG comprised 6% of the diet DM and corn silage was the major forage source. Milk fat yield was lower for cows receiving the 4% fat treatment ($P < 0.03$) when compared to the 2% fat treatment, but no effect of level of supplemental fat was observed for milk fat percentage. There was a fat source × level interaction for milk fat yield and milk fat percentage ($P < 0.01$). Cows fed 2% supplemental tallow produced less milk fat than cows fed 2% CWG, and at the 4% level of fat supplementation, cows receiving CWG had a lower milk fat yield than cows receiving tallow. We expected CWG to have a more negative impact on rumen fermentation and milk fat yield than tallow at both levels of supplementation. Regardless of its more unsaturated profile, feeding 2% CWG seems to have impaired to a lesser extent ruminal fermentation patterns when compared to feeding 2% tallow (Table 6). The reasons for this are not clear.

Milk protein yield tended to decrease ($P < 0.06$) with fat supplementation (Table 4). There was a significant effect ($P < 0.01$) of level of supplemental fat on milk protein yield (1.33 and 1.26 kg of CP/d for the 2 and 4% fat treatments, respectively); no effect of source of dietary fat was detected. Milk protein percentage increased ($P < 0.01$) with supplemental fat, but this increase was likely due to decreased milk production. A summary of the literature on fat supplementation showed a 0.15 percentage unit decrease in milk protein percentage when tallow was fed to dairy cattle (Shaver, 1990). Solids-not-fat content in milk was lower for control compared with fat supplemented cows (8.79 vs. 8.87%, respectively).

Milk Fatty Acid Composition

Fatty acid composition of milk fat is presented in Table 5. Overall, treatment effects on milk fatty acids in the present study were small. Relative percentage of milk fatty acids having 14 or fewer carbons was decreased with supplemental fat ($P < 0.01$), and this reduction tended to be more pronounced for CWG diets ($P < 0.09$). When supplemental fats are fed, the relative concentration of short-chain and medium-chain fatty acids decrease and that of long-chain fatty acids increase because de novo fatty acid synthesis and esterification in mammary tissue is reduced (Palmquist and Jenkins, 1980; Gaynor et al., 1995). However, the response of long-chain fatty acids to supplemental fat in this experiment was variable. There was no effect of fat supplementation on $C_{16:0}$ concentration in milk fat. Including fat in the diets increased milk fat concentration of $C_{18:0}$ ($P < 0.04$), and this increase was more marked for the CWG treatments ($P < 0.05$). The $C_{18:1}$ percentage in milk fat was increased ($P < 0.01$) when fat was supplemented, but no effect of source of dietary fat was detected. Concentration of $C_{18:2}$ and $C_{18:3}$ were decreased when fat was added to the diets. There was a significant effect ($P < 0.01$) of source of fat on milk fat $C_{18:2}$ concentration (3.6 vs. 3.9 g/100 g of fatty acid for tallow and CWG, respectively). The proportion of *cis*-9, *trans*-11 conjugated linoleic acid (**CLA**) was decreased ($P < 0.01$), whereas the proportion of the *trans*-10, *cis*-12 CLA isomer was not affected when supplemental fat was fed.

Of the $C_{18:1}$ isomers, both *cis*-9 and *cis*-11 isomers were increased by fat supplementation ($P < 0.01$). The *trans*-10 isomer increased when fat was added to the diets ($P < 0.01$), and it was higher in milk fat from CWG fed cows ($P < 0.03$) than from tallow-supplemented cows. When UFA were fed in combination with high grain-low fiber diets (14.8% NDF), the content of *trans*-10 in milk fat was dramatically increased (Griinari et al., 1998), and this increase was closely related to milk fat depression (**MFD**). In the present study,

Table 5. Least square means for milk fatty acid composition.

	Treatment						Statistical contrasts (P <)			
	Control	2% Tallow	2% CWG[1]	4% Tallow	4% CWG	SE	Control vs. Fat	Source	Level	Source × Level
Profile	(g/100 g of fatty acids)									
C_4 to C_{14}	24.0	19.7	19.3	18.7	17.8	0.7	0.001	0.09	NS[2]	NS
$C_{16:0}$	27.1	27.7	27.7	28.8	28.3	0.7	0.15	NS	NS	NS
$C_{18:0}$	8.4	9.3	9.6	8.7	9.0	0.4	0.04	0.05	NS	NS
$C_{18:1}$	24.9	27.9	30.5	29.7	28.5	0.9	0.001	NS	NS	0.04
$C_{18:1}$ isomers										
trans-6/8	0.61	0.75	0.83	0.75	0.71	0.11	NS	NS	NS	NS
trans-9	0.77	0.68	0.83	0.90	0.68	0.15	NS	NS	NS	NS
trans-10	1.20	2.10	2.33	1.85	2.05	0.15	0.001	0.04	0.09	NS
trans-11	0.73	0.56	0.48	0.46	0.37	0.04	0.001	0.02	0.05	NS
trans-12	0.32	0.30	0.26	0.34	0.29	0.08	NS	NS	NS	NS
trans-16	0.13	0.11	0.14	0.13	0.11	0.02	NS	NS	NS	NS
cis-9	19.2	21.6	23.9	23.5	22.7	0.9	0.001	NS	NS	0.09
cis-11	0.90	1.0	1.1	1.1	1.1	0.04	0.001	NS	0.03	NS
cis-12	0.47	0.22	0.21	0.17	0.15	0.03	0.001	0.07	NS	NS
CLA[3] c9t11	0.47	0.43	0.41	0.37	0.40	0.03	0.01	0.09	NS	NS
CLA t10c12	0.02	<0.01	<0.01	<0.01	<0.01	0.008	0.10	NS	NS	NS
$C_{18:2}$	5.1	4.0	4.1	3.2	3.7	0.2	0.001	0.002	0.11	NS
$C_{18:3}$	0.35	0.27	0.25	0.22	0.27	0.02	0.001	NS	NS	0.13
Total *trans*[4]	3.80	4.52	4.90	4.48	4.23	0.37	0.07	NS	NS	NS

[1]CWG = Choice white grease.
[2]NS = Nonsignificant.
[3]CLA = Conjugated linoleic acid.
[4]Total *trans* = $C_{18:1}$ isomers plus *trans*-10, *cis*-12 CLA.

the NDF content of the diets was much higher (average 29% NDF), which may have accounted for the smaller *trans*-10 increase compared with that observed by Griinari et al. (1998). Neither fat source in this study provided much $C_{18:2}$ to the diets, which is the source for *trans*-10, *cis*-12 CLA, and *trans*-10 $C_{18:1}$ in the rumen (Baumgard et al., 2000). The *trans*-11 isomer content of milk fat decreased with fat supplementation (P < 0.01) and was significantly lower for the CWG treatment than for the tallow treatment (0.42 and 0.52 g/100 g of fatty acid, respectively) (P < 0.02). Adding 4% dietary fat reduced *trans*-11 proportion relative to the 2% level of fat supplementation (P < 0.05). Contrary to our results, Griinari et al. (1998) observed a higher *trans*-11 $C_{18:1}$ content in milk fat when UFA were fed relative to when saturated fatty acids were fed. All other *trans*-$C_{18:1}$ isomers were unaffected by inclusion of fat in the diets. Total *trans* fatty acid (*trans*-$C_{18:1}$ plus *trans*-10, *cis*-12 CLA) concentration in milk fat tended to increase when tallow or CWG were supplemented (P < 0.07).

To investigate the possible role of *trans* FA in MFD, Griinari et al. (1998) plotted the change in *trans*-$C_{18:1}$ content in milk fat versus the change in milk fat percentage of cows fed a variety of diets, including low fiber diets or diets supplemented with different oil sources that observed a reduction in milk fat percentage. Although they found a negative relationship, that would be expected for several of the long-chain FA. During MFD, the proportion of short- and medium-chain FA in milk fat typically decreases while the proportion of most long-chain FA increases. Therefore, we evaluated the relationship between the ratio of *trans*-10 C_{18} FA (*trans*-10 $C_{18:1}$ plus *trans*-10, *cis*-12 $C_{18:2}$) to all other 18-carbon FA in milk fat versus milk fat percentage. This ratio attempts to evaluate the increase in *trans*-10 FA in milk fat independently of the overall increase in 18-carbon FA that occurs during MFD. We can conclude from Figure 1 that the increase in the proportion of *trans*-10 relative to all other 18-carbon FA is negatively related to milk fat percentage (R^2 = 0.4479, P < 0.0001).

Rumen Fermentation

Results of rumen measurements that are presented in Table 6 and discussed below correspond to data from cannulated animals (n = 5) that were analyzed by time as repeated measures. Data corresponding to the total number of animals used in the experiment (n = 15) at 4 h after feeding are similar to these results, unless otherwise noted. No treatment × time interactions were detected for any of the variables measured. Ruminal pH and total VFA concentration were not affected by fat supplementation (Table 6). There was a trend (P < 0.06) for total ruminal VFA to be higher for control

Table 6. Least square means for ruminal pH, concentration of total VFA and ammonia, and molar proportion of VFA.

	Treatments						Significant Contrasts ($P <$)			
	Control	2% Tallow	2% CWG[1]	4% Tallow	4% CWG	SE	Control vs. Fat	Source	Level	Source × Level
pH	6.2	6.3	6.3	6.2	6.3	0.1	NS[2]	NS	NS	NS
NH3-N, mg/dl	17.0	12.4	13.4	17.0	14.4	1.9	0.02	NS	0.01	0.07
Protozoa, $\times 10^5$/ml	7.5	3.2	5.5	1.9	2.6	0.8	0.01	0.12	0.04	NS
VFA, m*M*	119.6	115.6	113.4	112.6	108.4	4.2	0.06	NS	NS	NS
	mol/100 mol									
Acetate	58.0	52.6	54.7	50.2	50.4	1.03	0.01	0.10	0.01	NS
Propionate	22.9	30.8	28.0	30.9	31.9	1.33	0.01	NS	0.07	0.08
A:P[3]	2.56	1.73	2.00	1.65	1.61	0.12	0.01	NS	0.03	NS

[1]CWG = Choice white grease.

[2]NS = Nonsignificant.

[3]A:P = Acetate:propionate ratio.

cows relative to cows fed supplemental fat (this trend was not detected at 4 h after feeding). In general, fat supplementation has no impact on rumen pH and total VFA concentration (Pantoja et al., 1994). The molar proportion of ruminal acetate decreased, and the molar proportion of propionate increased when feeding supplemental fat; concomitantly, the acetate:propionate ratio (**A:P**) decreased ($P < 0.01$). There was a significant decrease in the proportion of acetate ($P < 0.01$), a trend ($P < 0.07$) towards an increase of propionate, and a significant decrease of A:P ($P < 0.03$) at the 4% level of fat supplementation relative to the 2% fat treatment. There were no significant effects of fat source on fermentation parameters. From an extensive review of the literature, Shaver (1990) concluded that

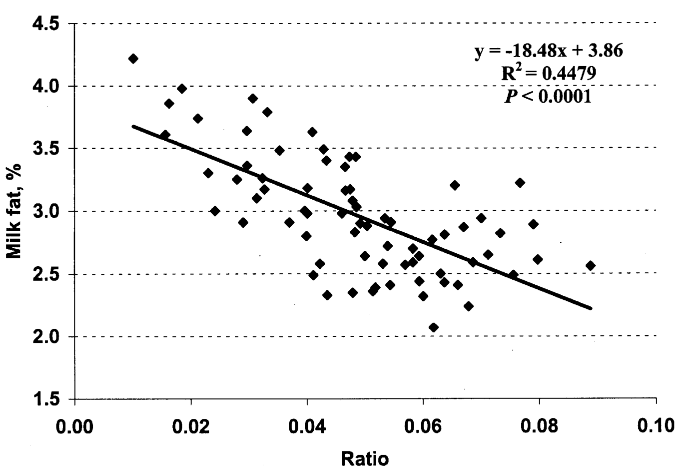

Figure 1. Relationship between the ratio of total *trans*-10 C_{18} fatty acids to all the remaining 18-carbon fatty acids in milk fat vs. milk fat percentage. The ratio = (*trans*-10 C18:1 + *trans*-10, *cis*-12 CLA)/($C_{18:0}$ + remaining of $C_{18:1}$ + $C_{18:2}$ + *cis*-9, *trans*-11 CLA + $C_{18:3}$). Each point represents data from an individual cow within a period.

there were minimal negative effects on rumen fermentation caused by feeding tallow at up to 5% of the diet, and that tallow was ruminally inert due to its more saturated profile. However, these observations are based on diets containing both alfalfa and corn silage as forage sources. In our study, both tallow and CWG significantly altered the VFA pattern at both levels of fat supplementation. The addition of CWG at 6% of dietary DM to corn silage-based diets decreased rumen acetate and increased propionate, leading to lower A:P (Tackett et al., 1996).

Dietary fat decreased ruminal NH_3-N relative to the control diet ($P < 0.02$) (Table 6). Surprisingly, feeding 4% supplemental fat resulted in a higher ($P < 0.01$) concentration of ammonia relative to feeding 2% fat. However, this was not the case when data from all the cows were included in the analysis (4 h postfeeding). The reduction in ruminal ammonia concentration when fat is included in dairy diets has been associated with reduced numbers of protozoa (Ikwuegbu and Sutton, 1982; Broudiscou et al., 1994) and decreased recycling of microbial nitrogen. In our study, fat supplementation lowered the protozoa numbers per milliliter of rumen fluid ($P < 0.01$) (Table 6). The reduction was most severe at the highest level of fat supplementation ($P < 0.04$). The effects of unsaturated fats on rumen protozoa are well documented. Ikwuegbu and Sutton (1982) observed a negative linear ($P < 0.01$) and quadratic ($P < 0.05$) response in protozoa numbers to increased amounts of supplemental linseed oil in the diets of sheep. Fat source did not influence protozoa numbers in this study. Both fat sources increased propionate concentration in the rumen, and propionate appears to inhibit protozoa (Firkins, 1996). The change in protozoa numbers is also consistent with the reduced A:P when feeding fats.

There was no treatment effect on in situ disappearance of corn silage DM and NDF (data not shown). Forty-eight hour ruminal DM and NDF degradation averaged 67.4 and 31.7%, respectively. These results agree with the results from Grummer et al. (1993), in which increasing tallow up to 5% of the diet DM did not adversely affect forage DM degradability in the rumen. Lewis et al. (1999) incubated TMR containing 5% tallow in the rumen of nonlactating Holstein cows and observed decreased DM and NDF degradability after 48 h of ruminal incubation relative to TMR containing 0% tallow (61.35 vs. 56.68 for DM for 0 and 5% tallow, respectively). In their review, Palmquist and Jenkins (1980) stated that feeding unprotected fats, especially if unsaturated, results in lower ruminal fiber degradability. Pantoja et al. (1994) showed a linear reduction in ruminal NDF digestion with increasing degree of fat unsaturation (51.4% for saturated tallow to 43.8% for animal-vegetable fat). There was no significant difference in the effects of tallow and CWG on corn silage DM and NDF degradability in this study. The lack of response is possibly due to the subtle difference in the fatty acid profile and degree of unsaturation of the fat sources used in this study.

CONCLUSIONS

Supplementing tallow and CWG to diets with corn silage as the sole forage source had negative effects on DMI, milk production, and milk fat percentage. We hypothesized that CGW would be more detrimental than tallow because of its higher unsaturated:saturated fatty acid ratio, but responses were similar between cows fed both fat sources. The cause for MFD is not clear in this trial. Rumen fermentation was impaired as indicated by a lower A:P and decreased protozoa numbers in the rumen of fat supplemented cows. However, there was no effect of supplemental fat on ruminal NDF degradation. Fat supplementation increased the proportion of *trans* fatty acids in milk fat, but this increase was small and showed a negative relationship to MFD. Further studies are required to identify dietary conditions that lead to negative animal responses when rendered fats are fed.

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