Calcium Salts of Fatty Acids in Diets that Differ in Neutral Detergent Fiber: Effect on Lactation Performance and Nutrient Digestibility[1]

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ABSTRACT

Total mixed rations containing 31 or 25% NDF were supplemented with 0 or .5 kg/cow per d Ca salts of fatty acids to study the effect of adding Ca salts of fatty acids to diets that differed in NDF content. Rations were fed for ad libitum intake to 12 early to midlactation Holstein cows in a replicated 4 x 4 Latin square design with a 2 x 2 factorial arrangement of treatments. No significant interactions were detected between Ca salts of fatty acids and ration NDF content. The Ca salts of fatty acids lowered milk protein percentage. Cows increased yield of milk, fat, and 4% FCM when they were fed Ca salts of fatty acids. Intake of DM and NEI increased when NDF was 25% rather than 31% of the total mixed ration. Milk from cows fed 25% NDF contained less fat and more protein. Yields of milk, fat, protein, and 4% FCM increased when diets contained 25% NDF. Conversion of DM intake to 4% FCM, however, decreased. Apparent digestibility of DM increased when diets contained 25% compared with 31% NDF. In this study, Ca salts of fatty acids increased yields of milk and 4% FCM, regardless of ration NDF content. Production increased but efficiency decreased when diets contained 25% vs. 31% NDF.

(Key words: calcium salts of fatty acids, neutral detergent fiber, digestibility)

INTRODUCTION

Researchers have successfully increased the energy density of diets for early lactation dairy cows with dietary fat (21). Dietary fat and its effect on animal performance and metabolism has been reviewed (6, 21). The use of dietary fat may continue to increase as the genetic potential for milk production is increased. Feeding large amounts of saturated and unsaturated fat, however, has detrimental effects on rumen metabolism and fiber digestibility, especially when intake is near, or slightly higher than, maintenance (4). The development of Ca salts of fatty acids (CaFA), which are considered inert in the rumen, offers a method of increasing production and efficiency without impairing fermentative digestion (4, 14).

An important consideration for successful and economical feeding of dietary fat is to maximize ration fiber (i.e., forage intake). A high roughage diet stabilizes rumen fermentation and helps to normalize rumen function when dietary fat is fed (19). Furthermore, fatty acids associate with feed particles in the rumen, reducing the potential inhibition of fat to microbes (13). Although research has examined the effect of feeding animal or vegetable fat in relatively high fiber (forage) diets, little research has been conducted to determine an optimum fiber when rumen-inert fat is fed. Currently, NDF is being utilized in formulating rations (17). Although the ideal ration NDF has not been determined, between 25 and 32% is being recommended for cows in early lactation (18). Adding rumen-inert fat may enhance energy intake and allow for increased use of forages in diets for lactating dairy cows. Objectives of this study were to evaluate the addition of rumen-inert fat to diets that differed in NDF content. Milk yield and composition, nutrient digestibility, and concentrations of selected blood metabolites were measured in Holstein cows in early to midlactation.

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MATERIALS AND METHODS

Animals and Treatments

Twelve early to midlactation Holstein cows (8 multiparous and 4 primiparous) were used in three 4 x 4 Latin squares with a 2 x 2 factorial arrangement of treatments. Animals were assigned to *the* three squares as follows: square 1, primiparous cows ranging from 42 to 57 d postpartum; square 2, multiparous cows ranging from 89 to 120 d postpartum; and square 3, rumen-cannulated, multiparous cows ranging from 132 to 156 d postpartum. Treatments (percentage of ration DM) were as follows: diet 1, 0% CaFA with 31% NDF; diet 2, 2.56% CaFA with 31% NDF; diet 3, 0% CaFA with 25% NDF, and diet 4, 2.56% CaFA with 25% NDF. As sampled, however, diets 2 and 4 contained only 1.2 percentage units more total fatty acid than diets 1 and 3 (Table 1). On a DM basis, diets 1 and 2 contained 70% alfalfa silage and 30% concentrate, and diets 3 and 4 contained 50% alfalfa silage and 50% concentrate. Fat (.5 kg/cow per d CaFA, Church and Dwight Co., Inc., Princeton, NJ) was added to the grain portion of diets 2 and 4 to total 7% ether extract (1) in the total ration DM.

Chemical analysis and chop length of the alfalfa silage are shown in Tables 2 and 3, respectively. For chop length determination, 400 g of wet alfalfa silage (representative samples from period 2 and 3) was dried (100°C) to a constant weight and manually separated according to length. Experimental periods were 21 d, with the last 10 d used for sample and data collection. Diets were formulated to meet or exceed NRC (18) requirements for cows weighing 600 kg and producing 34 kg milk/d. Diets were fed as total mixed rations twice

TABLE 1. Ingredient composition and analysis of diets (% DM).

	Diet[1]			
	1	2	3	4
Ingredient				
Alfalfa silage	70	70	50	50
Corn, dry shelled	28	24.83	42	3939
Soybean meal, 48%	.69	1.28	5.80	6.26
Monosodium phosphate 26% P	.66	.68	.61	.62
Limestone, 38% Ca	...	...	.85	.25
Magnesium oxide, 58% Mg	.04	.05	.08	.08
Salt, plain	.45	.45	.45	.45
Trace minerals	.04	.04	.05	.05
Se premix, .02% Se	.08	.08	.08	.08
Vitamin ADE[2]	.04	.04	.04	.04
Dynamate, 22% S	...	...	.01	.02
Ca Salt of fatty acid		2.56	...	236
Analysis				
DM	36	35.9	43.2	43.2
CP	19.6	19.5	18.8	18.6
Total fatty acid	1.84	3.05	1.71	2.89
Ether extract	5.3	7.1	4.9	6.8
NDF	31.2	31.1	25.2	25.1
ADF	25.0	25.0	18.7	18.7
Calcium	1.1	1.3	1.1	1.3
Phosphorus	.58	.58	.58	.6
Magnesium	.21	.21	.22	.22
Potassium	2.57	2.6	2.21	2.08
Estimated NES [3] Mcal/kg	1.58	1.64	1.67	1.75

[1]Diets (% of ration DM) are as follows: 1) 0% CaFA with 31% NDF; 2) 2.56% CaFA with 31% NDF; 3) 0% CaFA with 25% NDF; and 4) 2.56% CaFA with 25% NDF.

[2]Vitamin ADE supplement contained the following: 6.66×10^6 units/kg vitamin A, 3.33×10^6 units/kg vitamin D, and 1.33×10^4 units/kg vitamin E.

[3]Estimated value from NRC (18).

TABLE 2. Chemical analysis of alfalfa silage.[1,2]

Ingredient	Analysis
DM, %	35
CP, %	23
ADF, %	30
NDF %	36
NE1.[1] Mc al/kg	1.49
Total fatty acid, %	1.50
Calcium, %	1.6
Phosphorus, %	.45
Magnesium, %	.3

[1]0n a DM basis.

[2]Second cutting alfalfa.

[3]Estimated from NRC (18).

TABLE 3. Chop length of alfalfa silage.[1]

Chop length	Distribution[2]
(cm)	(%)
<1.3	69.8
1.3 to 2.5	16.7
2.5 to 5.0	9.7
>5.0	3.8

[1]Second cutting alfalfa.

[2]Percentage of total net dry weight.

daily (0630 and 1400 h) to allow 5 to 10% feed refusals. Amounts fed and refused were recorded daily. Body weights were recorded once weekly.

Sample Collection and Analysis

Dry matter content of feeds was determined weekly by oven drying (100°C), and diets were adjusted as necessary to maintain appropriate forage:concentrate ratios. Samples of alfalfa silage and concentrate(s) were obtained twice weekly and composited by period. Analysis for NDF and ADF were performed according to Goering and Van Soest (11). Ether extract was determined according to AOAC (1). Total fatty acid analysis was according to Sukhija and Palmquist (26). Crude protein was determined by Kjeldahl procedure (1). Mineral analysis was performed at The Pennsylvania State University Forage Testing Laboratory (wet chemistry). Feed refusals were sampled every other day during the sample collection portion of each experimental period and composited for each cow. Refusal samples were dried at 100°C for DM determination.

Milk yield was recorded daily during the last 10 d of each period. Cows were milked daily at 0530 and 1630 h. Composite p.m. to a.m. milk samples were collected every 3rd d during the 10-d sample collection period, proportioned according to volume, and analyzed (Foss 203B Milko-Scan, Foss Electric, Hillerod, Denmark) for fat and protein at The Pennsylvania DHIA Central Milk Testing Laboratory. Apparent digestibility of ration components was estimated using chromic oxide as an inert digestibility marker. During the last 10 d of periods 2 and 4, all cows received (immediately prior to fecal sampling) 10 g of chromic oxide (gelatin capsule), twice daily, via a balling gun. Fecal samples were collected twice daily at 0745 and 1745 h. Fecal samples were obtained directly from the rectum, dried at 100°C, and ground to pass a 1-mm screen. Ground samples were ashed at 600°C and prepared for Cr analysis according to Williams et al. (28). Chromium concentration was determined by atomic absorption spectrophotometry (Instrumentation Laboratory aa/ee Spectrophotometer 551, Lexington, MA), using a hollow cathode lamp, at 357.7 nm under a nitrous oxide-air acetylene flame (red cone of 20 mm). Samples of silage and concentrates were collected daily during fecal collection for DM, NDF, ADF, CP, and fat analysis.

Blood samples (30 ml) were collected by jugular venipuncture during the last day of each period at 0630 and 0930 h (0 and 3 h postfeeding, respectively). Samples were centrifuged at 3000 x *g* for 10 min, and plasma was collected and stored at —20°C for analysis of metabolites. Plasma was analyzed for blood urea nitrogen (BUN) by the method of Chaney and Marbach (5), glucose (glucose oxidase method, Sigma Technical Bulletin 510, Sigma Chemical Co., St. Louis, MO), nonesterified fatty acids (FFA) by an enzymatic colorimetric assay (Wako Chemicals USA, Inc., Dallas, TX), and triglycerides (enzymatic method, Sigma Technical Bulletin 336).

Statistical Analysis

Data were analyzed as a replicated 4 x 4 Latin square using the General Linear Models procedure of SAS (23). The treatment sequence that was selected minimized carry-over effects. Square (2 df), cow nested in square (9 df), period (3 df for intake, production, and blood data; 1 df for digestibility data), and treatment (3 cif) were sources of variation. The model employed for all statistical analysis was the following:

$$Y_{ijklm} = \mu + S_i + C_{j(i)} + P_k + T_1 + (ST)_{ii} + E_{ijkim}$$

where μ = overall mean, S_i = square effect, $q_{(1)}$ = effect of cow nested in square, Pk = period effect, Ti = treatment effect, (ST)ii = square x treatment interaction, and = experimental error. Means were compared by linear contrasts designed to test the following: CaFA versus no CaFA, 31% total ration NDF versus 25% total ration NDF, and the interaction of CaFA and total ration NDF. All data are expressed as least squares means.

RESULTS AND DISCUSSION

No interactions (P>.05) were detected between CaFA and ration NDF for any variable. Primiparous and multiparous cows responded similarly to the experimental treatments (i.e., no square x treatment interactions). Effect of CaFA and ration NDF on DM intake and lactation performance appears in Table 4. Intakes of DM (kg/d or percentage of BW) and NEI (Mcal/d) were not affected by the addition of CaFA. Others have reported no effect of rumen-inert fat on the intake of DM or NEI (12, 25, 30).

Addition of CaFA did not affect milk fat percentage (3.73 vs. 3.65%) but lowered (P<.01) milk protein percentage (3.10 vs. 3.03%). Adding dietary fat or CaFA to rations fed to lactating dairy cows depressed milk protein percentage in other studies (12, 16). The reason for decreased milk protein percentage with added fat is poorly understood, but it may be related to decreased casein nitrogen (9, 10). Regardless of amount of NDF in the ration, cows increased (P<.04) yield of milk (29.8 vs. 28.7 kg), fat (1.15 vs. 1.05 kg), and 4% FCM (28.5 vs. 27.1 kg) when they were fed CaFA (Table 4). Conversion of DM intake to 4% FCM also increased (P<.01) when cows were fed CaFA (1.50 vs. 1.40). In other studies, rumen-inert fats increased milk yield an average of 1.6 kg/d, but this increase has not always been statistically significant (12, 16, 24, 25). Yields of 3.5% FCM, fat, and protein by midlactation cows was not affected by CaFA supplementation in recent studies by Schauff and Clark (24) and Grummer (12).

Intake of DM (kg/d or percentage of BW) and NEI were higher (P<.01) when total mixed rations contained 25% NDF than 31% NDF (21.3 vs. 18.2 kg). This response, in part, may be related to ration DM content as well as ration NDF content. The moisture in diets 1 and 2 (31% NDF) was 7 percentage units higher than the moisture in diets 3 and 4 (25% NDF). Ration DM content can affect feed intake (18). With midlactation cows, Woodford et al. (29) observed no differences in total DM intake when diets contained between 21 and 30% total ration NDF, but intake of NDF increased linearly as percentage of forage in the diet increased. In (29), alfalfa hay was the sole forage source. As expected, cows consumed more (P<.04) NDF (kg/d) in our study when diets contained 31% NDF (Table 4).

Cows fed 25% total ration NDF secreted less (P<.03) fat (3.60 vs. 3.77%) and more (P<.01) protein (3.11 vs. 3.02%) in milk (Table 4). Milk fat percentage was decreased in midlactation cows with decreased forage (NDF) feeding (29). In the study by Woodford et al. (29), milk protein percentage decreased when total ration NDF was 24.2% compared with 27.4 or 30.1% NDF. In our study, milk protein percentage increased when diets contained 25 vs. 31% NDF. This effect may be related to increased protein intake when diets contained 25% NDF (Table 4), although protein requirements were adequately met (18) for all cows. Additionally, diets 3 and 4 contained proportionally more shelled corn and soybean meal than diets 1 and 2 (Table 1). Combined with increased fermentable organic matter intake, increased protein intake could allow for increased flow of amino acids to the duodenum. As a result, an improved pattern of amino acids available for milk protein synthesis may have existed when diets contained 25 vs. 31% NDF.

Yields of milk (31.0 vs. 27.5 kg), fat (1.15 vs. 1.05 kg), protein (.97 vs. .83 kg), and 70% FCM (29.1 vs. 26.5 kg) were higher when diets contained 25% NDF than when they contained 31% NDF (Table 4). Efficiency of DM utilization (4% FCM/kg DM intake), however, de-

TABLE 4. Effect of calcium salts of fatty acids (CaFA) and ration NDF content on dry matter intake and lactation performance.

Variable	Diet[1]				SE	Significance of contrast[2] (P<)	
	1	2	3	4		CaFA	NDF
Intake							
DM, kg/d	18.1	18.2	21.8	20.7	.49	.29	.01
DM, % BW	2.9	3.0	3.6	3.4	.08	.16	.01
NES[3] Mcal/d	28.6	29.8	36.7	36.1	.8	.53	.01
NDF, kg/d	5.63	5.65	5.49	5.20	.15	.31	.04
NDF, % BW	.92	.93	.91	.86	.02	.44	.05
CP, kg/d	3.54	3.54	4.09	3.84	.09	.18	.01
Milk composition, %							
Fat	3.75	3.79	3.54	3.66	.07	.29	.03
Protein	3.05	2.98	3.15	3.07	.02	.01	.01
Yields, kg/d							
Milk	27.0	28.0	30.4	31.6	.48	.03	.01
Fat	1.0	1.1	1.1	1.2	.03	.04	.02
Protein	.82	.83	.96	.97	.02	.43	.01
4% FCM	26.0	26.9	28.2	30.0	.61	.03	.01
BW, kg	606	604	606	601	3.1	.17	.63
Efficiency							
4% FCM/kg DM intake	1.48	1.53	1.32	1.47	.04	.01	.01

[1]Diets (% of ration DM) are as follows: 1) 0% CaFA with 31% NDF, 2) 2.56% CaFA with 31% NDF; 3) 0% CaFA with 25% NDF; and 4) 2.56% CaFA with 25% NDF.

[2]No significant (P>.05) CaFA x NDF interactions.

[3]Calculated from NRC (18).

creased as dietary NDF decreased. Milk production and milk composition were not different when alfalfa silage or corn silage diets contained 32% NDF (7). Briceno et al. (3) suggested that NDF has a greater impact on DM intake than on milk yield. Mertens (17) evaluated four concentrations of total ration NDF (35 to 55%) and reported a curvilinear response in DM intake, milk yield, and 4% FCM; production of 4% FCM was highest when rations contained 35% NDF. Others have reported no relationship *between total* diet NDF and milk yield (3, 29). In the present study, CaFA and ration NDF had no effect on mean BW.

The effect of Ca salts of fatty acids and ration NDF on nutrient digestibility is shown in Table 5. Apparent digestibilities of DM, CP, NDF, or ADF were not affected by the addition of CaFA. There was a trend for increased apparent digestibility of fat (P<.08) with CaFA supplementation. Calcium salts of fatty acids (.58 to .68 kg/cow per d) have not been demonstrated to affect ruminal disappearance of DM or NDF (12, 24) or total tract digestibility of DM, protein, NDF, or ADF (12, 14, 24). Calcium salts of fatty acids have increased the apparent digestibility of total lipid in other studies when compared with digestibility of control rations (12, 14). The improved digestibility of total lipid suggests that added fat is perhaps more digestible than the lipid fraction of an unsupplemented diet. Grummer (12) hypothesized that supplemental fat dilutes endogenous lipid secretions, resulting in a more accurate estimate of true lipid digestibility. Researchers have observed a depression in fiber digestibility when feeding rumen-unprotected sources of fat (4). The inhibitory effect of lipids on fiber digestibility is reduced when intake is near or greater than three times maintenance (27), perhaps due to an increased passage rate.

Apparent digestibility of DM was higher (P<.04) when diets contained 25% NDF rather than 31% NDF (Table 5). Total ration NDF did not influence the apparent digestibility of CP,

TABLE 5. Effect of calcium salts of fatty acids (CaFA) and ration NDF content on digestibility of ration components.

Variable	Diet[1] 1	2	3	4	SE	Significance of contrast[2] (P<) CaFA	NDF
Apparent digestibility, %							
DM	61.4	62.7	67.5	65.3	1.7	.83	.04
CP	68.5	69.1	70.2	67.7	1.7	.65	.95
Fat	53.8	65.4	58.0	64.8	3.3	.08	.56
NDF	32.2	38.4	39.9	37.2	3.4	.70	.37
ADF	38.5	41.1	44.2	40.1	2.8	.84	.44

[1]Diets (% of ration DM) are as follows: 1) 0% CaFA with 31% NDF, 2) 236% CaFA with 31% NDF; 3) 0% CaFA with 25% NDF; and 4) 2.56% CaFA with 25% NDF.

[2]No significant (P>.05) CaFA x NDF interactions.

fat, NDF, and ADF. Apparent digestibility of DM, CP, NDF, and ADF were not different when diets contained between 21 and 30% NDF in a study by Woodford et al. (29). Delaney et al. (8) reported that the digestibility of DM by early lactation cows tended to decrease as dietary NDF (32, 34, and 36%) increased. When sheep were fed alfalfa leaves, leaves plus stems, and stems, increased dietary cell wall content was related to decreased digestibilities of DM, energy, and NDF (22).

Concentrations of glucose and BUN were not affected by CaFA or ration NDF (Table 6). Plasma triglyceride (35.7 vs. 30.7 mg/l00 mg) and FFA (164.4 vs. 146.1 p.eq/L) concentration increased (P<.04) as a result of CaFA supplementation. The effect of feeding rumen-protected fat on plasma glucose concentration is variable (2, 15, 25). Others have shown an increase in plasma triglyceride and FFA concentration with rumen-inert (2, 25) and rumen-unprotected (20) fats. Although ration NDF did not influence triglycerides, cows fed the high fiber diet (31% NDF) tended to have higher (P<.08) concentrations of FFA (163.1 vs. 147.5 Req/L) in plasma. Cows consumed less energy when diets contained 31% NDF, perhaps the result of increased mobilization of FFA from adipose tissue.

CONCLUSIONS

Responses of early lactation cows to CaFA were consistent with results from other studies. Feeding CaFA resulted in increased yield of milk, fat, and 4% FCM and decreased milk protein percentage. Efficiency of feed utilization also increased when CaFA were fed. The two concentrations of dietary NDF had little influence on the response of cows to CaFA,

TABLE 6. Effect of calcium salts of fatty acids (CaFA) and ration NDF content on concentration of plasma metabolites.

Variable	Diet[1] 1	2	3	4	SE	Significance of contrast[2] (P<) CaFA	NDF
Glucose, mg/100mg	77.7	77.8	78.2	78.1	1.1	.99	.72
BUN,[3] mg/100mg	20.5	21.4	20.9	20.7	.6	.58	.79
Triglyceride, mg/100mg	30.7	35.9	30.7	35.4	.6	.01	.68
FFA,[4] meq/L	151.3	174.8	140.9	154.0	8.7	.04	.08

[1]Diets (percentage of ration DM) are as follows: 1) 0% CaFA with 31% NDF; 2) 2.56% CaFA with 31% NDF; 3) 0% CaFA with 25% NDF; and 4) 2.56% CaFA with 25% NDF.

[2]No significant (P>.05) CaFA x NDF interactions.

[3]Blood urea nitrogen.

[4]Nonesterified fatty acids.

suggesting that CaFA can be added to high forage diets and that production can be maintained. Although feed intake and milk production increased when diets contained 25% NDF, efficiency (4% FCM/kg DM intake) of feed utilization decreased.

Mertens (17) indicated that the optimum daily intake of NDF for dairy cows is 1.1% of BW. Mertens' system is designed to maximize the forge content of dairy rations formulated to meet, not exceed, energy requirements. In the present study, consumption of NDF by cows was approximately .9% of BW (Table 4). Energy requirements (18) were theoretically met when diets contained 31% NDF but were likely exceeded when diets contained 25% NDF. The relationship between dietary NDF and energy intake (NEI) needs to be addressed. In this short-term experiment, yields of milk and 4% FCM were maximized when diets contained 25% compared with 31% NDF.

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