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Effect of Varying Levels of Fatty Acids from Palm Oil on Feed Intake and Milk Production in Holstein Cows

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ABSTRACT

To determine the optimum feeding level of fatty acids of palm oil (PALM; Energizer RP10; 86.6% palmitic acid) on milk production, lactating cows (n = 18) were randomly assigned to a treatment sequence in replicated 4 × 4 Latin squares. Animals were assigned to squares by parity (3 multiparous and 1 primiparous squares with primiparous in the incomplete square). The 4 diets were designed to provide 0, 500, 1,000, and 1,500 g of PALM per day. Cows were fed individually with feed intake measured daily. Each period lasted 16 d with milk production and composition determined the final 2 d. Milk production, milk composition and feed intake data were analyzed using the MIXED procedure of SAS. Milk yields were 30.9, 34.0, 34.2, and 34.2 kg/d (SEM = 1.9) for the 0, 500, 1,000, and 1,500 g levels, respectively. Milk yield was increased by the addition of PALM; however, there were no differences among the levels of PALM. Milk fat percentage was also increased from 3.44% for 0 g to 3.95% (SEM = 0.17) across all levels of PALM but there were no differences among the PALM treatments. Dry matter intakes were 23.3, 26.4, 24.7, and 23.8 kg/d (SEM = 1.4) for the 0, 500, 1,000 and 1,500 g levels, respectively. The addition of PALM increased milk yield and milk fat percentage, and no adverse effects on dry matter intake were observed.

Key words: palmitic acid, milk yield, dry matter intake, fatty acid

INTRODUCTION

The addition of supplemental fats to dairy rations has been utilized for a number of years to increase the energy density of the diet and increase milk yield (Jenkins and McGuire, 2006). However, the effects on DMI, milk yield, milk fat, and milk protein have been variable. The variation observed with fats is likely a result of a number of factors including source and form of the fat, stage of lactation, and DMI (Chilliard, 1993). Unsaturated fatty acids often have negative impacts on rumen function and DMI (Jenkins and Jenny, 1989; Pantoja et al., 1994). As a result, much work (see review by Jenkins and McGuire, 2006) has been focused on methods to include additional fat in the diet without altering rumen function. Two strategies have been utilized to incorporate additional fat without altering rumen function: 1) feeding highly saturated fatty acids, and 2) protecting unsaturated fatty acids from microbial alterations.

In an effort to keep feed costs low, it may be beneficial to use fats that require little processing before feeding. Therefore, animal rendering or plant oil production by-products can be cost effective. However, with the recent concerns of bovine spongiform encephalopathy, it may be advantageous to limit animal by-products in dairy rations. In July 2005, the FDA proposed banning some tallow products for use in ruminant feeds (FDA, 2005). As a result, a low cost, highly saturated, plant-based fat source could gain acceptance in the dairy industry.

Although it is generally accepted that producing milk fat with lower concentrations of saturated fatty acids is beneficial, there may also be a role for milk fat with higher concentrations of saturated fatty acids. The functionality of fats varies depending on the end user of the product. For example, commercial users of butter (i.e., the bakery industry) desire a firmer butter to produce a flakier or crispier product, whereas the home consumer of butter desires a softer, more spreadable product (Kaylegian, 1999). In some cases it may be beneficial to produce different products at the farm level rather than through processing.

The purpose of this work was to determine the optimum feeding level of a by-product of the palm oil industry (a highly saturated, plant-based fat supplement) on DMI, milk yield, milk components, and milk fatty acid profile in dairy cattle.

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Table 1. Composition of the TMR[1]

Ingredient	% of DM
Alfalfa hay	24.0
Alfalfa silage	20.0
Steam-rolled corn	26.2
Soy hulls	10.4
Corn distillers grain	5.2
Grass hay	5.1
Vitamin mix[2]	0.3
Trace mineral salt[3]	0.8
Dicalcium phosphate	0.4
Sodium bicarbonate	0.5
Magnesium oxide	0.3

[1]Treatments consisted of the basal ration plus fatty acids of palm oil (Energizer RP-10, IFFCO, Johor, Malaysia) to target intakes of 500, 1,000, and 1,500 g/d.

[2]Vitamin mix contained 30,096 kIU/kg vitamin A, 26,400 kIU/kg vitamin D and 499 kIU/kg vitamin E in a ground barley carrier.

[3]Trace mineral salt contained 900 g/kg salt, 100 g/kg Mg, 100 g/kg Zn, 940 mg/kg Fe, 3,170 mg/kg Mn, 2,050 mg/kg Cu, 380 mg/kg I, 120 mg/kg Se, and 100 mg/kg Co.

Table 2. Nutrient composition of treatment diets on a DM basis[1]

	Targeted daily intake of fatty acids of palm oil[2]			
Variable	0	500	1,000	1,500
DM, %	55.0	55.4	55.8	56.2
CP, g/kg	184	173	176	174
ADF, g/kg	285	288	281	273
NDF, g/kg	387	386	378	359
Fatty acids,[3] g/kg	23	31	52	72
Ash, g/kg	98	86	82	80
NE_L,[4] Mcal/kg	1.67	1.75	1.83	1.91

[1]Values represent the mean of 4 samples composited by treatment within each period and then again by treatment across the experiment.

[2]Energizer RP-10, IFFCO, Johor, Malaysia.

[3]Calculated from fatty acid analysis procedure.

[4]Estimated from laboratory analysis.

MATERIALS AND METHODS

Animals, Treatments, and Experimental Design

All animal procedures were preapproved by the University of Idaho Animal Care and Use Committee. Mid-lactation Holstein cows (DIM = 146 ± 12; n = 18) were randomly assigned to a treatment sequence in a 4 × 4 Latin square design. Cows were assigned to squares by parity resulting in 3 complete squares of multiparous cows, 1 complete square of primiparous cows, and 1 incomplete square of primiparous cows. Periods consisted of 16-d intervals after which the cows were moved to the next treatment without a washout period. Cows were housed in sand-bedded freestalls and individually fed via Calan gates (American Calan Inc., Northwood, NH). Diets were fed once daily at 0700 h for ad libitum consumption. Feed refusals were weighed daily before the morning feeding and intake was determined. Cows were milked twice daily at 0400 and 1600 h.

Dietary treatments were formulated to meet NRC nutrient requirements (NRC, 2001) and consisted of no supplemental fat and 3 levels of fatty acids of palm oil (**PALM**; Energizer RP-10, IFFCO, Johor, Malaysia) added to the basal diet (Table 1). The PALM supplement consisted of 86.6% palmitic acid, 4.2% myristic acid, 4.1% oleic acid, 2.8% stearic acid, and 2.3% lauric acid. The amount of PALM was adjusted daily to target intakes of 0, 500, 1,000, and 1,500 g/d. Samples from each of the 4 diets were taken every 4 d throughout each period.

Samples of TMR were dried at 55°C to determine DM and ground through a 1.0-mm screen. Dried ground TMR samples were composited by treatment within each period and then again by treatment across the experiment. Chemical composition of the TMR was analyzed for CP, ADF, NDF, and ash by near infrared analysis (Table 2; Dairyland Laboratories, Arcadia, WI). An aliquot of the composited TMR samples was stored for fatty acid analysis. Fatty acid content of TMR was calculated from the fatty acid analysis procedure (Table 3).

Milk production and composition were determined during the final 2 d of each period. Milk was sampled using proportional milk samplers and the a.m. and p.m. milkings were pooled daily. Milk was analyzed for fat, true protein, lactose, SCC, and SNF by near infrared analysis (Washington DHI, Burlington, WA). An aliquot of milk from each of the last 2 d of the period was used for fatty acid analysis.

Table 3. Fatty acid intake (wt % of total fatty acids, g/d) while consuming diets containing varying levels of fatty acids of palm oil[1]

	Targested daily intake of fatty acids of palm oil[2]				
Fatty acid	0	500	1,000	1,500	SEM
12:0	0.8	2.2	3.9	5.0	0.1
14:0	2.4	15.0	29.7	41.5	0.2
16:0	111.6	429.0	808.2	1,139.8	5.4
18:0	23.5	22.4	27.6	34.6	0.5
18:1 *cis*-9	78.0	80.2	106.6	133.8	1.2
18:1 *cis*-11	4.8	4.5	5.6	6.9	0.1
18:2 n-6	239.5	199.8	231.2	253.1	4.5
18:3 n-3	47.5	41.3	44.7	44.4	1.3
20:0	2.5	2.1	2.2	2.4	0.04
20:5 n-3	0.4	0.2	0.3	0.3	0.05
22:6 n-3	1.4	1.3	1.4	1.6	0.1
24:0	3.9	3.0	3.3	3.6	0.2

[1]Values represent the mean fatty acid concentratioin for each treatment TMR times the mean DMI for each treatment for 4 TMR samples composited within each period.

[2]Energizer RP-10, IFFCO, Johor, Malaysia.

Table 4. Response of feed intake, milk yield, and composition to varying levels of fatty acids of palm oil[1]

	Targest daily intake of fatty acid of palm oil[2]					Effect of diet[3]	
Variable	0	500	1,000	1,500	SEM	Linear	Quad
PALM intake,[4] g/d	0[a]	476[b]	887[c]	1248[d]	37	<0.0001	NS
DMI, kg/d	23.3[a]	26.4[b]	24.7[ab]	23.8[a]	1.4	NS	<0.02
Milk yield, kg/d	30.9[a]	34.0[b]	34.2[b]	34.2[b]	1.9	<0.001	NS
Fat, %	3.44[a]	3.93[b]	4.06[b]	3.88[b]	0.17	<0.02	NS
Fat yield, g/d	1,018[a]	1,304[b]	1,320[b]	1,411[b]	105	<0.001	NS
True protein, %	2.98	2.97	2.94	2.90	0.07	0.08	NS
Protein yield, g/d	881[a]	971[b]	950[b]	988[b]	56	<0.01	NS
Lactose, %	4.53	4.53	4.51	4.43	0.07	NS	NS
SNF, %	8.36	8.37	8.32	8.18	0.10	0.08	NS
SCC, $\times 10^3$/mL	140	158	145	150	48	NS	NS

[a–d]Means within a row with different superscripts differ ($P < 0.05$).

[1]Values represent means of samples taken on d 15 and 16 from each cow (n = 18; SCC, n = 16).

[2]Energizer RP-10, IFFCO, Johor, Malaysia.

[3]Degrees of freedom for effects of diet were partitioned into linear and quadratic (Quad) contrasts. NS = nonsignificant effect.

[4]Actual intake of fatty acids of palm oil (PALM) adjusted for DMI.

Lipid Analyses

Milk lipids were extracted using 2:1 chloroform:methanol (Clark et al., 1982) and methylated using base-catalyzed transesterification (Christie, 1982). Ground oven-dried TMR samples (500 mg) were methylated in a 2-step procedure using methanolic HCl and sodium methoxide according to Kramer et al. (1997). The fatty acid methyl esters were analyzed on a gas chromatograph (Hewlett-Packard 6890 series with auto injector) fitted with a flame-ionization detector and a 100 m × 0.25 mm (0.2 μm film) capillary column coated with CP-Sil 88 (Chrompack, Middelburg, the Netherlands). After sample injection, the oven temperature was 70°C for 3 min and then increased to 175°C at a rate of 3°C/min and held for 3 min. Oven temperature was then increased to 185°C at a rate of 1°C/min and held for 20 min, increased to 215°C at a rate of 3°C/min, and then increased to 230°C at a rate of 10°C/min and held for 5 min. To quantify fatty acids, response correction factors were determined by the analysis of a butter oil standard with certified values (CRM 164; European Community Bureau of Reference, Brussels, Belgium).

Statistical Analyses

Feed intake, milk production, composition, and fatty acid data were analyzed as a 4 × 4 Latin square design using the MIXED procedure of SAS (Version 9.1, SAS Inst., Inc., Cary, NC). Sources of variation in the model included effects of experimental period, dietary treatment, and residual error. Cow was designated as a random effect in the model. Two cows had consistently elevated SCC and were not included in the analysis for SCC. In an effort to examine the response surface for level of PALM, degrees of freedom were partitioned into linear and quadratic contrasts. Additionally, means were compared using single degree of freedom contrasts. When a significant effect ($P < 0.05$) of dietary treatment was observed, means were compared using the Dunnett's test.

RESULTS

Dry matter intake (Table 4) was maximized ($P < 0.001$) with 500 g of PALM. A quadratic effect ($P < 0.032$) of level of PALM on DMI showed that DMI increased with the 500 g/d diet but then decreased for the 1,000 and 1,500 g/d diets to levels similar to the control. Due to changes in DMI, actual intakes of PALM were 0, 478, 888, and 1,275 g/d for the 0, 500, 1,000, and 1,500 g/d dietary treatments, respectively; less than originally targeted.

Milk yield (Table 4) was increased ($P < 0.001$) from 30.9 kg/d for the control to approximately 34 kg/d across all intakes of PALM. No differences were detected among the 3 levels of PALM supplementation. Similarly, milk fat percentage ($P < 0.02$) and milk fat yield ($P < 0.001$) were increased with the addition of PALM but no differences were detected for milk fat among PALM-supplemented diets. Although a trend ($P < 0.08$) for a linear decrease in milk protein percentage was detected with increasing PALM intake, milk protein yield was increased ($P < 0.01$) when cows were supplemented with PALM. Supplementation with PALM did not affect lactose percentage or SCC (Table 4).

Concentrations of milk fatty acids were affected by the addition of PALM (Table 5). As the intake of pal-

Table 5. Fatty acid profile of milk from cows consuming diets containing varying levels of fatty acids of palm oil[1]

	Targest daily intake of fatty acids of palm oil[3]					Effects of diet[4]	
Fatty acid[2]	0	500	1,000	1,500	SEM	Linear	Quad
4:0	2.95	3.09	3.09	3.03	0.07	NS	NS
6:0	2.02[a]	1.88[b]	1.77[c]	1.72[c]	0.04	<0.0001	NS
8:0	1.18[a]	0.99[b]	0.89[c]	0.85[d]	0.03	<0.0001	NS
10:0	2.68[a]	2.12[b]	1.85[c]	1.78[c]	0.08	<0.0001	NS
12:0	3.06[a]	2.42[b]	2.11[c]	2.04[c]	0.09	<0.0001	NS
14:0	9.79[a]	8.63[b]	7.96[c]	7.89[c]	0.16	<0.0001	NS
14:1 *cis*-9	0.85	0.85	0.82	0.82	0.05	NS	NS
15:0	0.99[a]	0.83[b]	0.72[c]	0.66[d]	0.01	<0.0001	NS
16:0	30.70[a]	39.14[b]	43.96[c]	45.56[d]	0.44	<0.0001	NS
16:1 *cis*-9	2.24[a]	2.86[b]	3.35[c]	3.64[d]	0.12	<0.0001	NS
17:0	0.56[a]	0.42[b]	0.35[c]	0.30[d]	0.009	<0.0001	NS
18:0	9.12[a]	6.83[b]	5.79[c]	4.95[d]	0.24	<0.0001	NS
18:1 *cis*-9	21.22[a]	19.30[b]	17.86[c]	17.39[c]	0.43	<0.0001	NS
Trans 18:1	2.26[a]	1.79[b]	1.54[c]	1.44[d]	0.04	<0.0001	NS
Cis 18:1	1.19[a]	0.97[b]	0.88[c]	0.89[c]	0.03	<0.0001	NS
18:2 n-6	3.59[a]	3.17[b]	2.99[c]	3.11[b]	0.08	<0.0001	NS
18:3 n-3	0.50[a]	0.41[b]	0.36[c]	0.36[c]	0.01	<0.0001	0.06
Cis-9, *trans*-11 CLA	0.46[a]	0.40[b]	0.34[c]	0.30[d]	0.01	<0.0001	NS
20:0	0.10[a]	0.08[b]	0.07[c]	0.05[d]	0.001	<0.0001	NS
20:4 n-6	0.12[a]	0.10[b]	0.09[c]	0.10[b]	0.004	<0.0001	NS
Others	4.20[a]	3.58[b]	3.20[c]	3.19[c]	0.06	<0.0001	NS
SFA	65.51[a]	68.35[b]	70.18[c]	70.38[c]	0.48	<0.0001	NS
MUFA	28.53[a]	26.48[b]	25.14[c]	24.87[c]	0.46	<0.0001	NS
PUFA	5.96[a]	5.17[b]	4.68[c]	4.74[c]	0.10	<0.0001	NS
Desat	24.78[a]	23.42[b]	22.36[c]	22.15[c]	0.44	<0.0001	NS
De novo	21.69[a]	19.14[b]	17.66[c]	17.31[c]	0.35	<0.0001	NS
CLA	0.52	0.45	0.38	0.34	0.01	<0.0001	NS

[a–d]Means within a row with different superscripts differ ($P < 0.05$).

[1]Values given are weight percentage of total fatty acids present in milk collected on d 15 and 16 by cow (n = 18) of each period.

[2]*Trans* 18:1 = all *trans* 18:1 isomers; *cis* 18:1 = all *cis* 18:1 isomers excluding *cis*-9 18:1; SFA = total saturated fatty acids; MUFA = total monounsaturated fatty acids; PUFA = total polyunsaturated fatty acids; Desat = sum of *cis*-9 14:1, *cis*-9 16:1, *cis*-9 18:1, and *cis*-9, *trans*-11 CLA (products of the Δ^9-desaturase enzyme); De novo = sum of 6:0, 8:0, 10:0, 12:0, 14:0; CLA = sum of all conjugated linoleic acid isomers.

[3]Energizer RP-10, IFFCO, Johor, Malaysia.

[4]Degrees of freedom for effects of diet were partitioned into linear and quadratic (Quad) contrasts. NS = nonsignificant effect.

mitic acid increased with the PALM diets, milk palmitic acid concentrations were increased ($P < 0.0001$). When 1,500 g/d of PALM was consumed, milk palmitic acid concentration was increased by 50% compared with the control. This increase was countered by a general decrease in the weight percentage of many other fatty acids. Weight percentages of many short- and medium-chain fatty acids including 6:0, 8:0, 10:0, 12:0, and 14:0 were decreased ($P < 0.0001$). Similarly, decreases were detected for stearic, oleic acid, linolenic acid, and *cis*-9, *trans*-11 conjugated linoleic acid (**CLA**) concentrations with increasing amount of PALM intake. Increasing PALM intake caused an increase in the concentration of total saturated fatty acids (**SFA**) and a decrease in total monounsaturated (**MUFA**) and polyunsaturated (**PUFA**) fatty acids found in the milk.

To a lesser extent the yield of individual fatty acids was also altered by the addition of PALM (Table 6), the major difference being an increase ($P < 0.001$) in SFA driven by the linear increase of palmitic acid. Similarly, *cis*-9 16:1 yield doubled compared with controls when 1,500 g/d of PALM was fed. Feeding PALM appeared to have no effect on the total yield of the Δ^9-desaturase products, because the sum of the products of the Δ^9-desaturase enzyme in milk was unchanged. Total MUFA and PUFA yields were also unaltered.

DISCUSSION

Milk Production and Components

Lactation responses to dietary fat supplementation have been variable and were dependent on fat source, stage of lactation, and DMI (Coppock and Wilks, 1991). Typically, unprotected unsaturated fats have a negative effect on milk yield whereas rumen inert fats (i.e.,

prilled fats, calcium salts of fatty acids) often have a positive effect on milk yield (Chilliard, 1993). The PALM fed in the current study was highly saturated and should have little impact on rumen fermentation. Increasing the energy concentration of the TMR through the supplementation of PALM resulted in a 3 kg/d increase in milk yield when compared with the control. Although milk yield was similar across dietary levels, DMI decreased with greater additions of PALM above 500 g/d.

Several studies examined the effects of palmitic acid on milk and milk fat yield. Steele (1969) replaced 10% of concentrate with palmitic acid (approximately 525 g/d), which resulted in an increase of milk yield from 13.6 to 14.6 kg/d when compared with a low fat (1.94%) control diet. Similarly, the supplementation of 517 g/d of palm oil containing 62% palmitic acid resulted in a 20% increased milk fat percentage and a 25% increase in milk yield with no adverse effects on milk protein (Banks et al., 1976a). These results are similar to those in the current study. In contrast, Steele and Moore (1968) reported no change in milk yield when 10% of the concentrate was isocalorically replaced with palmitic acid but milk fat percentage increased from 3.31% in controls to 4.17% when palmitic acid was added, resulting in an 88 g/d increase in milk fat yield. In cows given duodenal infusions of 500 g/d of palmitic acid (98% purity), milk yield was not altered, but milk fat percentage was increased from 3.57 to 4.55% in cows supplemented with palmitic acid (Enjalbert et al., 2000). Similar to the other feeding trials with palmitic acid, milk protein was not altered.

DMI

When evaluating the impact of supplemental dietary palmitic acid on DMI it is difficult to make ideal comparisons because of the few investigations evaluating high palmitic acid intake. However, the effects of supplemental fat on DMI were evaluated and were variable, usually resulting in no change or a decrease in DMI (Chilliard, 1993). The increase observed in DMI (Table 4) when 500 g of PALM was fed was unexpected. However, DMI returned to the level of controls when 1,000 and 1,500 g/d of PALM were fed. Similarly, Firkins and Eastridge (1994) observed a negative relationship between DMI and fatty acid content. However, the relationship was not significant until the proportion of fatty acids in the diet was 3.5 percentage points greater than the control (Firkins and Eastridge, 1994). The increase in DMI when 500 g/d of PALM was fed may also be partially explained by the high fiber content of the TMR (Table 2; 28% ADF and 38% NDF). For example, supplemental fat (2.5%) tended to increase DMI in diets that contained 29% ADF and 45% NDF, whereas DMI trended downward when supplemental fat was incorporated into diets that contained only 19% ADF and 34% NDF (Elliott et al., 1995).

Generally, DMI increases linearly as the degree of saturation increases (Pantoja et al., 1994). Comparing tallow to partially hydrogenated tallow, DMI was greater for the more saturated partially hydrogenated tallow than for tallow (Pantoja et al., 1994, 1996). Similar increases in DMI have also been observed when hydrogenated yellow grease was compared with commercial yellow grease (Jenkins and Jenny, 1989). Elliott et al. (1996) observed a trend for highly saturated fats (>80%) to increase DMI when compared with a calcium salt that was 53% saturated. However, in this instance, neither fat supplement decreased DMI when compared with the control. On the contrary, a linear trend for saturated (86%) fat prills to decrease DMI from 15.2 to 14.0 kg/d was observed as levels of fat intake increased from 0 to 9% (DM basis) of the TMR (Ferguson et al., 1990). We observed little effect on DMI when supplemental fat intake was increased from 0 to 3% (as-fed basis) of TMR with greater intakes (24.4 vs. 14.4 kg/d) than those reported by Ferguson et al. (1990). The variation in diets and fat source may explain this discrepancy. The diets fed by Ferguson et al. (1990) contained only 40% forage compared with 50% in the current study and the fat source contained 14% oleic acid whereas the PALM fat used contained only 4.1% oleic acid.

Milk Fatty Acids

Grummer (1991) demonstrated that de novo fatty acid synthesis decreased linearly as supplementation of dietary fat increased, and that the changes in palmitic and stearic acids were dependent on the ratio in the added fat. The present work agrees with these findings because the concentration (Table 5) of de novo fatty acids decreased linearly as PALM supplementation increased. However, the yield (Table 6) of de novo fatty acids was unchanged, which is accounted for by the increase in milk yield. Both milk palmitic acid concentration and yield increased in a linear fashion as intake of PALM increased. Steele and Moore (1968) reported reductions in concentration and yield of short- and medium-chain fatty acids (4:0 to 14:0) and dramatic increases in palmitic acid with increased dietary intake of palmitic acid; the concentration of palmitic acid in milk increased from 38.7% in controls to 60.7% in the cows supplemented with palmitic acid. All 18-carbon fatty acids decreased (Steele and Moore, 1968), which agrees with the current observations in which there were decreases in 18-carbon fatty acids including stea-

Table 6. Fatty acid yield (g/d) of milk from cows consuming diets containing varying levels of fatty acids of palm oil[1]

	Targeted daily intake of fatty acids of palm oil[3]					Effects of diet[4]	
Fatty acid[2]	0	500	1,000	1,500	SEM	Linear	Quad
4:0	28.5[a]	38.9[b]	39.8[b]	40.2[b]	3.23	<0.0004	NS
6:0	19.7	23.9	23.2	23.3	2.12	NS	NS
8:0	11.5	12.5	11.6	11.66	1.13	NS	NS
10:0	26.3	26.8	24.8	24.7	2.52	NS	NS
12:0	29.9	30.3	27.7	28.1	2.76	NS	NS
14:0	95.9	107.9	103.5	105.6	8.81	NS	NS
14:1 *cis*-9	8.3[a]	10.5[b]	10.5[b]	10.7[b]	0.95	<0.004	NS
15:0	9.6	10.2	9.2	8.9	0.76	NS	NS
16:0	298.6[a]	486.9[b]	566.1[bc]	603.4[c]	42.7	<0.0001	NS
16:1 *cis*-9	21.9[a]	34.5[b]	42.9[c]	47.9[c]	3.42	<0.0001	NS
17:0	5.4[a]	5.1[a]	4.3[b]	4.0[b]	0.33	<0.0001	NS
18:0	88.3[a]	84.6[a]	73.7[b]	64.9[b]	6.07	<0.0001	NS
18:1 *cis*-9	204.0	232.5	224.6	225.7	14.7	NS	NS
Trans 18:1	22.1	22.4	19.8	19.1	1.71	NS	NS
Cis 18:1	11.6	11.7	11.2	11.8	0.91	NS	NS
18:2 n-6	35.0	39.3	38.4	41.2	3.23	NS	NS
18:3 n-3	4.9	5.2	4.6	4.7	0.41	NS	NS
Cis-9, *trans*-11 CLA	4.4	4.8	4.2	4.0	0.35	NS	NS
20:0	0.96[a]	0.96[a]	0.83[b]	0.70[c]	0.06	<0.0001	NS
20:4 n-6	1.1	1.2	1.1	1.3	0.09	NS	NS
Others	40.4	44.3	40.9	41.8	3.14	NS	NS
SFA	637.6[a]	851.7[b]	905.5[b]	935.6[b]	70.6	<0.0001	NS
MUFA	275.3	320.4	317.9	324.4	21.6	NS	NS
PUFA	57.9	63.8	59.9	62.8	4.85	NS	NS
Desat	238.7	282.5	282.3	288.3	18.8	NS	NS
De novo	211.9	240.5	230.4	233.6	20.3	NS	NS
CLA	5.0	5.5	4.8	4.5	0.38	NS	NS

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

[1]Values given are yields (g/d) of total fatty acids present in milk collected on d 15 and 16 by cow (n = 18) of each period.

[2]*Trans* 18:1 = all *trans* 18:1 isomers; *cis* 18:1 = all *cis* 18:1 isomers excluding *cis*-9 18:1; SFA = total saturated fatty acids; MUFA = total monounsaturated fatty acids; PUFA = total polyunsaturated fatty acids; Desat = sum of *cis*-9 14:1, *cis*-9 16:1, *cis*-9 18:1, and *cis*-9, *trans*-11 CLA (products of the Δ^9-desaturase enzyme); De novo = sum of 6:0, 8:0, 10:0, 12:0, 14:0; CLA = sum of all conjugated linoleic acid isomers.

[3]Energizer RP-10, IFFCO, Johor, Malaysia.

[4]Degrees of freedom for effects of diet were partitioned into linear and quadratic (Quad) contrasts. NS = nonsignificant effect.

ric acid, oleic acid, linoleic acid, and *cis* and *trans* isomers of octadecenoic acid. Similar changes in milk fatty acids were observed when the concentrate mixture contained 10% (approximately 500 g/d) palmitic acid (Noble et al., 1969); short- and medium-chain fatty acids (6:0 to 14:0) decreased when compared with a no-fat control. Moreover, concentrations of stearic and linoleic acids were decreased; however, on a yield basis, only linoleic acid was decreased when high levels of palmitic acid were fed (Noble et al., 1969). Milk palmitic acid was increased from 36.4% in controls to 49.8% of all fatty acids in palmitic acid treated cows. Banks et al. (1976b) also observed decreases in short- and medium-chain fatty acids in milk (6:0 to 14:0), with increases observed in concentrations of palmitic, palmitoleic, and oleic acids.

Concentrations of palmitic acid were highest when 1,500 g/d of PALM was fed, reaching a concentration of 45.5%. Using duodenal infusions of 500 g of palmitic acid (98% purity), Enjalbert et al. (2000) reported that concentrations of palmitic acid in milk were increased 30% compared with controls, which is similar to the 27% increase we observed when 500 g/d of PALM was fed. Enjalbert et al. (2000) observed decreases in myristic acid, stearic acid, oleic acid, total unsaturated 18-carbon fatty acids, and total 18-carbon fatty acids whereas concentrations of caproic acid, caprylic acid, lauric acid, and *trans* 18:1 were unaltered. On a yield basis, however, only palmitic acid was different from controls.

Increasing the unsaturated fat in diets leads to more biohydrogenation in the rumen, which results in increased *trans* fatty acids in milk fat (Bauman and Griinari, 2003). Because of the high SFA content of the diets containing the PALM supplement (Table 3), it was believed that the concentrations of *cis*-9, *trans*-11 CLA

and *trans* isomers of 18:1 may be affected. In fact, the concentrations of *cis*-9, *trans*-11 CLA and *trans* 18:1 isomers in milk fat were linearly decreased by the addition of PALM but the yield of these fatty acids was unchanged. This agrees with the findings of Harvatine and Allen (2005), who reported increasing concentrations of *cis*-9, *trans*-11 CLA and *trans* 18:1 fatty acids in milk fat as the intake of unsaturated fatty acids increased. Yellow grease, containing higher portions of unsaturated fatty acids, has also been shown to increase the concentrations of *trans*-9 18:1 and *trans*-11 18:1 when compared with tallow (Avila et al., 2000).

CONCLUSIONS

Milk yield, milk fat percentage, and milk fat yield increased in a linear fashion as the intake of palmitic acid increased. There were no negative effects of fat supplementation on protein or lactose percentage and milk protein yield increased with fat supplementation. Increasing the intake of palmitic acid from 0 to 500 g/d increased DMI, whereas feeding 1,000 or 1,500 g/d of supplemental fat had no effect on DMI compared with the unsupplemented diet. On a weight percentage basis, milk fat contained more SFA and less MUFA and PUFA. This was primarily driven by the dramatic increase in palmitic acid concentration. Yield of SFA was also increased but there were no changes in the yield of MUFA and PUFA. Adding high levels of palmitic acid can be an effective method to increase energy intake without the negative effects on DMI, milk fat, or milk protein.

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