Effect of saturated fatty acid supplementation on production and metabolism indices in heat-stressed mid-lactation dairy cows

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ABSTRACT

Experimental objectives were to determine the effects of supplemental saturated fatty acids on production, body temperature indices, and some aspects of metabolism in mid-lactation dairy cows experiencing heat stress. Forty-eight heat-stressed Holstein cows were allocated into 3 groups ($n = 16/\text{group}$) according to a completely randomized block design. Three treatment diets consisted of supplemental saturated fatty acids (SFA) at 0 (SFA0), 1.5 (SFA1.5), or 3.0% (SFA3) of dry matter (DM) for 10 wk. Diets were isonitrogenous (crude protein = 16.8%) and contained 1.42, 1.46, and 1.49 Mcal of net energy for lactation/kg of DM for the SFA0, SFA1.5 and SFA3 diets, respectively. The average temperature-humidity index at 0700, 1400 and 2200 h was 72.2, 84.3, and 76.6, respectively. Rectal temperatures at 1400 h were decreased with fat supplementation. Treatment did not affect dry matter intake ($20.1 \pm 0.02 \text{ kg/d}$), body condition score (2.72 ± 0.04), body weight ($627 \pm 16.1 \text{ kg}$), or calculated energy balance ($1.32 \pm 0.83 \text{ Mcal/d}$). Saturated fatty acid supplementation increased milk yield, milk fat content, and total milk solids. Increasing fat supplementation decreased plasma nonesterified fatty acids (8%) but had no effect on other energetic metabolites or hormones. In summary, supplemental SFA improved milk yield and milk fat content and yield and reduced peak rectal temperatures in mid-lactation heat-stressed dairy cows. This demonstrates the remarkable amount of metabolic heat that is “saved” by energetically replacing fermentable carbohydrates with supplemental SFA.

Key words: saturated fatty acid, heat stress, milk yield, metabolism

INTRODUCTION

Heat stress negatively affects a variety of aspects in the dairy industry and is therefore a significant financial burden in many dairy-producing areas of the world. Heat stress reduces feed intake, rumination, and nutrient absorption, and increases maintenance requirements (Beede and Collier, 1986). Collectively these changes cause heat-stressed lactating cows to enter into a calculated negative energy balance (Moore et al., 2005; Schwartz et al., 2009) and probably decrease the nutrient and energy availability for milk production.

Dietary strategies to alleviate this energy deficit traditionally include increasing the energy density of the diet with concentrates or fat supplements (Knapp and Grummer, 1991; Chan et al., 1997; Drackley et al., 2003). However, high concentrate diets or adding oils rich in unsaturated fatty acids may adversely affect rumen health (Maia et al., 2007), especially during heat stress (Kadzere et al., 2002). Compared with unsaturated fatty acids, saturated fatty acids (SFA) are thought to be less detrimental to rumen fermentation because they do not negatively influence bacterial plasma membrane function to the same extent (Jenkins, 1993). Additionally, the high caloric value of fats allows them to be conveniently incorporated into the diet to increase the ration energy density without substantially increasing the heat increment of fermentation. Our study objectives were to determine the effects of supplemental SFA on lactation performance, body temperature indices, and metabolism in mid-lactation dairy cows experiencing heat stress.

MATERIALS AND METHODS

Animals and Experimental Design

All procedures involving animals were approved and conducted according to standards of the Institute of Animal Science, Chinese Academy of Agricultural Sci-

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Table 1. Ingredient and chemical composition of diets

Composition	Treatment ¹		
	SFA0	SFA1.5	SFA3
Ingredient (% of DM)			
Corn stover silage	26.85	26.81	26.76
Chinese wildrye	4.13	4.12	4.12
Alfalfa hay	10.33	10.31	10.29
Wheat dregs	2.82	2.82	2.81
Corn	21.72	20.00	18.28
Barley	1.88	1.88	1.88
Soybean meal (49.7% CP)	8.19	8.51	8.83
Extruded soybeans	2.64	2.64	2.64
Cottonseed meal	3.55	3.54	3.54
Dry distillers grains	8.06	8.05	8.04
Calcium carbonate	0.87	0.87	0.87
Dicalcium phosphate	1.02	1.02	1.02
Salt	0.40	0.40	0.40
Sodium bicarbonate	0.74	0.74	0.74
Vitamin/mineral premix ²	0.45	0.45	0.45
Magnesium oxide	0.19	0.19	0.19
Potassium chloride	0.38	0.38	0.38
Apple meal	5.78	5.77	5.76
Saturated fatty acid ³	0.00	1.50	3.00
Chemical ⁴			
NE _L ⁵ (Mcal/kg)	1.42	1.46	1.49
CP	16.87	16.85	16.84
NDF	36.73	36.58	36.44
ADF	21.62	21.58	21.55
Ether extract	4.66	6.08	7.49
Lignin	6.30	6.28	6.27
Ca	0.78	0.78	0.78
P	0.52	0.52	0.51

¹Cows were fed a basal diet (SFA0) or basal diet supplemented with 1.5% saturated fatty acid (SFA1.5), or 3% saturated fatty acid (SFA3).

²Contains (per kg of premix): 4,560 mg of Cu, 4,590 mg of Mn, 12,100 mg of Zn, 200 mg of Se, 270 mg of I, 60 mg of Co, 2,000,000 IU of vitamin A, 450,000 IU of vitamin D, 10,000 IU of vitamin E, 3,000 mg of niacin.

³Saturated fatty acid was Advance Energy Booster-100 (Milk Specialties Global Animal Nutrition, Carpentersville, IL).

⁴Units are % of DM, unless stated otherwise.

⁵Calculated according to NRC (2001) based on actual DMI.

ences, Beijing, China. Forty-eight lactating Holstein dairy cows (184 ± 17 DIM, 30.8 ± 3.3 kg of milk/d, and 2.2 ± 1.5 parity) were blocked by parity (primiparous or multiparous), average daily milk yield, and DIM, and randomly assigned to 1 of 3 treatments according to a completely randomized block design. Cows were experiencing heat stress before the experiment: temperature-humidity index (THI) and ambient temperature averaged = 81.2 and 29.7°C , respectively for 30 d before experiment initiation; rectal temperature and respiration rates averaged 39.3°C and 74 breaths/min (bpm) during the week before the start of the experiment.

Cows were fed 1) a control diet without SFA addition (SFA0), 2) the control diet with 1.5% SFA (SFA1.5), or 3) the control diet with 3% SFA (SFA3) on a DM basis. The lipid supplements energetically replaced di-

etary corn. Advance Energy Booster 100 (Milk Specialties Global Animal Nutrition, Carpentersville, IL) was the SFA used, which contained 99.1% total fatty acids as 1.3% C14:0, 54% C16:0, 34% C18:0, 8% C18:1, 1.2% C18:2, and 0.6% other fatty acids. The SFA supplement was assigned an NE_L content of 5.81 Mcal/kg based on the Cornell Net Carbohydrate and Protein System (CNCPS; Version 6.1, Cornell University, Ithaca, NY). Ingredient and chemical composition of diets are presented in Table 1.

Diets were formulated to meet or exceed recommendations for all nutrients as specified by China Feeding Standard (2004) for dairy cattle. All 3 diets were formulated to be isonitrogenous (16.8% CP), and dietary NE_L values were 1.42, 1.46, and 1.49 Mcal/kg, for the SFA0, SFA1.5, and SFA3, respectively. Cows were fed the basal diet for wk 1 of the experiment, followed by 9 wk on the treatment diets. The TMR was offered at 0530, 1300, and 2000 h to ensure 10% orts, and the SFA supplements were top-dressed in equal portions at 0600 and 2030 h. Cows were individually fed and had free access to water.

Cows were housed in tie-stalls in a mechanically ventilated barn and randomly distributed throughout one section of the barn. Ventilation consisted of a series of 10 overhead fans (diameter = 50 cm, 1.0 kW power) placed approximately every 6 m along the barn and a large fan (diameter = 70 cm, 1.2 kW power) directing outside air down the alley between the 2 rows of outward-facing cows.

Sampling, Measurements, and Analyses

Feed offered was measured daily, and feed refused was measured on Monday, Wednesday, and Friday of each experimental week. Samples of offered TMR were collected daily and frozen at -20°C . Orts were sampled from each cow, composited for each treatment, and frozen at -20°C until further analysis. Weekly representative samples of TMR and orts from each treatment were analyzed for DM content. The DM content of the feed ingredients was determined by drying in a forced-air oven at 60°C for 48 h. Dietary formulations were adjusted weekly during the experiment to account for changes in ingredient DM content. Daily DMI for individual cows was calculated by subtracting the orts from the feed offered. The NE_L content of the diet was determined by inputting feed analyses in CNCPS (Version 6.1).

Weekly dried feed samples were ground through a Cyclotec 1903 mill (Tecator 1093, Tecator AB, Hoganas, Sweden) using a 1-mm screen and analyzed for composition. The CP content of feed samples was determined using the macro-Kjeldahl nitrogen test (AOAC, 2000;

method 954.01) with a Kjeltec digester 20 and Kjeltec System 1026 distilling unit (Tecator AB). Contents of NDF, ADF, and acid detergent lignin were determined using the basic procedure of Van Soest et al. (1991). Sodium sulfite was not used in the procedure for NDF determination, but heat-stable amylase (type XI-A from *Bacillus subtilis*; Sigma Aldrich Corp., St. Louis, MO) was added to the substrate before the procedure. Crude ash (550°C for 8 h), ether extract, calcium, and phosphorus were also determined (AOAC, 1990).

Cows were milked 3 times daily at 0700, 1400, and 2100 h. Milk yield was recorded weekly from individual cows. Milk samples (70 mL) from individual cows were collected from 3 consecutive milkings and composited by each milking (morning, afternoon, and night; 4:3:3 by vol) on the seventh day of every week. Milk samples were analyzed for fat, protein, lactose, total solids, MUN, and SCC using mid-infrared spectrophotometry (BactoScan FC CombiFoss 6000, Foss Electric, Hillerød, Denmark).

At 0 (end of standardization period), 21, 42, and 63 d, blood samples were collected in serum separator tubes (Serum Clot Activator, Greiner BioOne GmbH, Kremsmunster, Austria) from the coccygeal vein or artery at 3 h after the morning feeding. Blood samples were allowed to clot for a minimum of 5 h on ice and then centrifuged at $3,000 \times g$ for 15 min at 4°C. Blood serum samples were stored at -70°C until further analysis. Serum was analyzed for NEFA (FA115 kit, Randox Laboratories Ltd., Antrim, UK; Johnson and Peters, 1993), BHBA (RB1007 kit, Randox Laboratories Ltd.; McMurray et al., 1984) and glucose (442640 kit, Beckman Instruments B.V., Mijdrecht, the Netherlands; Raabo and Terkildsen, 1960). Insulin concentration was determined using an RIA kit (Coat-a-Count Insulin, Diagnostic Products Corp., Los Angeles, CA). The accuracy of each assay was monitored with the use of a commercial reference serum sample (Bovine precision serum, Randox Laboratories Ltd.) and the outcome deviated less than 5% from the target values.

Cows were measured for heart girth and body length at the end of wk 1 and wk 10 at 1300 h. Body weight was calculated using the follow equation: $BW \text{ (kg)} = \text{heart girth}^2 \text{ (m)} \times \text{body length (m)} \times 90$ (Wang, 2006). Body condition scores were assigned weekly by 3 experienced individuals, using a 5-point scale (1 = thin to 5 = obese; Wildman et al., 1982).

Rectal temperatures and respiration rates were measured at 0730, 1400, and 2200 h on Monday, Wednesday, and Friday of each week. The respiration rates were determined by counting the number of flank movements in a 15-s period and multiplying this by 4 to determine breaths per minute.

Net energy intake (NE_I) was determined by multiplying DMI by the calculated energy density of the diet. The equation $NE_M \text{ (Mcal/d)} = 0.08 \times BW^{0.75}$ was used to compute energy required for body maintenance (NE_M) and increased 20% as recommended by Fox and Tylutki (1998) during heat stress. The equation $NE_L \text{ (Mcal/d)} = M \times [(0.0929 \times F) + (0.0563 \times P) + (0.0395 \times L)]$ was used to calculate milk energy, where M is milk production (kg), F is fat percentage in the milk, P is true protein percentage in the milk, and L is lactose percentage in the milk (NRC, 2001). Energy balance (EB) was calculated weekly using the equation $EB \text{ (Mcal/d)} = NE_I - (NE_M + NE_L)$.

The equation $SCM \text{ (kg/d)} = 12.3 \text{ (FY)} + 6.56 \text{ (SNF)} - 0.0752 \text{ (M)}$ was used to calculate solids-corrected milk (SCM), where FY, SNF, and M are expressed as kilograms of fat, solids-not-fat, and milk, respectively (Tyrrell and Reid, 1965). Production efficiency was calculated as total solids yield/DMI (kg/kg) and SCM/NE_L intake (kg/Mcal).

The local climate data were collected from China mobile news service. The environmental temperature and humidity of pens were recorded daily (0700, 1400, and 2200 h), and measured with a thermometer and hygrometer, respectively, within one instrument panel (Beijing Yaguang Equipment Co. Ltd., Beijing, China). Cows were randomly distributed in one section of the barn, and measurements were taken at 3 times daily in 3 locations (at each end of the barn and in the middle). Temperature-humidity index in the barn was generated using the following formula (National Oceanic and Atmospheric Administration, 1976): $THI = td - (0.55 - 0.55 RH) \times (td - 58)$, where td is dry-bulb temperature (in °F) and RH is relative humidity. The experiment was conducted between July 26 and October 6, 2007.

Statistical Analyses

Data were analyzed by repeated measures using the PROC MIXED procedure of SAS (SAS Institute, 2005) and the covariance structure used to best fit the model was selected based on Akaike's information criterion. The model contained time, treatment, and time $\times$ treatment interaction. Cow and block were random effects. Time (hour of day for body temperature indices and week for all other parameters), treatment, and time $\times$ treatment interaction were the fixed effects. The BW data were analyzed based on 2 measurements (wk 1 and 10). Two contrast statements were used to interpret treatment effects. The first contrast examined the effect of supplemental saturated fat (FAT) or SFA0 compared with SFA1.5 and SFA3. The second contrast determined the level of supplemental saturated fat

Figure 1. Temporal temperature-humidity index (THI) pattern at 0700, 1400, and 2200 h and mean during the 10-wk experimental period. Thresholds for no stress, mild stress, and high stress are from Armstrong (1994).

(LEVEL) or SFA1.5 compared with SFA3.0. Values are presented as least squares means with their standard error of the mean. Significance was declared at $P < 0.05$, and trends were discussed at $P < 0.15$.

RESULTS

Heat Stress Measures and THI

Mean daily ambient temperatures in the barn were 26.8°C (range 22.0 to 31.3°C) at 0700 h, 30.0°C (range 23.3 to 35.0°C) at 1400 h, and 26.4°C (range 20.7 to 30.7°C) at 2200 h. The mean THI was 72.2 (range 66.1 to 77.7) at 0700 h, 84.3 (range 77.4 to 89.6) at 1400 h, and 76.6 (range 69.1 to 82.3) at 2200 h (Figure 1).

There were no treatment effects ($P > 0.05$) on overall respiration rates or rectal temperature; however, there were significant effects based on time of day ($P < 0.01$) for both body temperature and respiration rate (Table 2). Cows fed SFA had decreased rectal temperatures at 1400 h ($P < 0.05$; Table 2) compared with controls. Respiration rate was not different among treatments during any time of the day (Table 2). There was a tendency for increased respiration rate at 2200 h when SFA was fed ($P < 0.10$; Table 2).

DMI, Milk Yield, and Milk Composition

Dietary treatment had no effect on DMI (Table 3). Saturated fatty acid supplementation increased ($P < 0.05$) milk yield and SCM (Table 3). Milk fat yield and percentage was increased by feeding SFA ($P < 0.05$). Cows fed SFA had increased ($P < 0.05$) milk protein,

lactose, and total solids yield, whereas there was only a tendency for increased total solids content ($P < 0.11$; Table 3). Milk protein, lactose, and total solids contents tended to increase with increased level of fat supplementation ($P < 0.15$). There was no diet effect on MUN concentration or SCS; however, SFA supplementation tended to decrease SCS ($P < 0.10$; Table 3).

Efficiency and EB

Feeding supplemental SFA improved production efficiency measured as SCM/NE_L intake and total solids yield/DMI ($P < 0.02$; Table 3). Dietary treatment had no effect on calculated EB (Table 3), BW gain (10, 12, and 23 kg for SFA0, SFA1.5, and SFA3, respectively), or BCS (2.73, 2.71, and 2.72 for SFA0, SFA1.5, and SFA3, respectively).

Metabolites and Metabolic Hormones

Cows fed SFA had decreased ($P < 0.03$) NEFA levels, and there was a tendency for NEFA to decrease further with the level of fat fed ($P < 0.10$; Table 4). There was no dietary difference in serum concentrations of glucose, BHBA, or insulin (Table 4). All serum metabolites and metabolic hormones measured varied over time ($P < 0.01$; Table 4).

DISCUSSION

Dairy cattle reduce feed intake, ruminate less, and have increased maintenance requirements when the THI

Table 2. The effects of supplemental saturated fatty acids on body temperature variables in mid-lactation dairy cows during heat stress

Variable	Treatment ¹				P-value ³				
	SFA0	SFA1.5	SFA3	SEM ²	Trt	Time	Int	Fat	Level
Rectal temperature (°C)									
0700 h	38.44	38.73	38.86	0.16	0.11	0.01	0.01	0.05	0.53
1400 h	39.79	38.98	39.21	0.15	0.01	0.01	0.01	0.01	0.23
2200 h	39.01	39.13	39.18	0.11	0.46	0.01	0.01	0.23	0.75
Average	39.08	38.94	39.08	0.13	0.64	0.01	0.01	0.65	0.41
Respiration rate (breaths/min)									
0700 h	57.93	59.97	60.27	1.58	0.52	0.01	0.02	0.26	0.89
1400 h	67.15	67.98	68.56	1.81	0.86	0.01	0.28	0.62	0.82
2200 h	61.73	65.11	65.26	1.73	0.27	0.01	0.01	0.10	0.95
Average	62.27	64.35	64.70	1.64	0.53	0.01	0.04	0.27	0.88

¹Cows were fed a basal diet (SFA0) or basal diet supplemented with 1.5% saturated fatty acid (SFA1.5), or 3% saturated fatty acid (SFA3).

²Pooled standard error of least squares means.

³Trt = treatment effect; Time = effect of time of day; Int = interaction between treatment × time; Fat = effect of SFA supplements; Level = effect of SFA supplemental level.

reaches or exceeds 72 (Armstrong, 1994). In the current study, maximum THI averaged 84.3, and minimum THI averaged 72.2 (Figure 1); both are well above the minimum needed to induce heat stress. Furthermore, respiration rates averaged more than 60 bpm, and rectal temperature averaged more than 38.9°C; both are characteristic of heat-stressed dairy cattle (Kadzere et

al., 2002). Cows fed additional SFA had similar rectal temperatures in the morning and late in the evening, but during the hottest part of the day (1400 h), cows fed SFA had reduced rectal temperatures. The reduced body temperature in the SFA-fed cows was presumably due to the lower heat increment of these diets because other heat-influencing measures (e.g., DMI, milk yield,

Table 3. The effect of supplemental saturated fatty acids on production variables in mid-lactation heat-stressed dairy cows

Variable	Treatment ¹				P-value ³				
	SFA0	SFA1.5	SFA3	SEM ²	Trt	Week	Int	Fat	Level
Production measures									
DMI (kg/d)	20.2	20.1	20.2	0.1	0.87	0.01	0.65	0.63	0.84
Milk yield (kg/d)	26.4	28.6	28.5	0.6	0.02	0.01	0.15	0.01	0.91
SCM ⁴ (kg/d)	25.4	28.4	29.1	1.0	0.01	0.01	0.35	0.01	0.59
NE _L intake ⁵ (Mcal/d)	31.0	32.0	33.7	0.1	0.01	0.01	0.78	0.01	0.52
SCM/NE _L intake (kg/Mcal)	0.81	0.89	0.88	0.03	0.07	0.01	0.90	0.02	0.77
Total solids yield/DMI (kg/kg; %)	16.2	17.9	18.4	0.6	0.01	0.01	0.61	0.01	0.49
Energy balance ⁶ (Mcal/d)	1.60	0.25	1.22	0.8	0.37	0.07	0.57	0.31	0.33
Components									
Milk fat									
%	3.37	3.67	3.81	0.13	0.08	0.01	0.05	0.03	0.47
g/d	881	1,048	1,091	53	0.02	0.01	0.21	0.01	0.54
Milk protein									
%	3.03	2.90	3.06	0.06	0.18	0.01	0.01	0.50	0.09
g/d	787	827	865	26	0.04	0.01	0.24	0.03	0.20
Milk lactose									
%	4.81	4.82	4.92	0.05	0.19	0.01	0.01	0.29	0.09
g/d	1,266	1,375	1,398	46	0.04	0.01	0.78	0.01	0.68
Milk total solids									
%	12.52	12.66	13.01	0.16	0.09	0.01	0.15	0.11	0.13
g/d	3,281	3,617	3,706	120	0.04	0.01	0.53	0.01	0.60
MUN (mg/dL)	15.0	15.6	15.2	0.65	0.85	0.01	0.01	0.67	0.73
SCS ⁷	3.68	2.88	2.92	0.39	0.26	0.08	0.81	0.10	0.94

¹Cows were fed a basal diet (SFA0) or basal diet supplemented with 1.5% saturated fatty acid (SFA1.5), or 3% saturated fatty acid (SFA3).

²Pooled standard error of least squares means.

³Trt = treatment effect; Week = effect of week; Int = interaction between treatment × time; Fat = effect of SFA supplements; Level = effect of SFA supplemental level.

⁴SCM = solids-corrected milk (Tyrrell and Reid, 1965).

⁵NE_L intake calculated according to NRC (2001).

⁶Energy balance calculated according to NRC (2001), representing an average during the experiment.

⁷SCS = Log₂ (SCC/100,000) + 3.

Table 4. The effects of supplemental saturated fatty acids on metabolic indices in mid-lactation heat-stressed dairy cows

Blood parameter	Treatment ¹				P-value ²				
	SFA0	SFA1.5	SFA3	SEM	Trt	Week	Int	Fat	Level
NEFA (μ Eq/L)	376.3	358.7	329.8	12.4	0.03	0.01	0.51	0.03	0.10
Glucose (mg/dL)	55.2	54.8	53.7	1.0	0.49	0.01	0.49	0.40	0.38
BHBA (mmol/L)	0.69	0.68	0.72	0.03	0.30	0.01	0.01	0.72	0.13
Insulin (μ IU/mL)	15.1	17.2	16.3	1.1	0.31	0.01	0.49	0.16	0.58

¹Cows were fed a basal diet (SFA0) or basal diet supplemented with 1.5% saturated fatty acid (SFA1.5), or 3% saturated fatty acid (SFA3).

²Trt = treatment effect; Week = effect of week; Int = interaction between treatment $\times$ time; Fat = effect of SFA supplements; Level = effect of SFA supplemental level.

and BW) were either unchanged or increased in the cows fed SFA. Presumably, the reduced body temperature in SFA-fed cows represents the amount of metabolic heat that is saved by energetically replacing fermentable carbohydrates with supplemental SFA.

Previous experiments indicate that supplemental fat can benefit heat-stressed cows. Skaar et al. (1989) reported that high-producing (>35 kg/d of milk), early lactation cows fed 5% SFA during warm season months (April to August) produced markedly more milk than cows not receiving SFA. Drackley et al. (2003) observed a 1.9 kg/d milk yield response when mid-lactation cows were fed diets with supplemental fat (3% DM, as choice white grease) during the summer. In the present study, cows fed supplemental SFA produced approximately 2 kg more milk than did control cows. However, there was no increased milk response when increasing the level of SFA from 1.5 to 3.0% of DM. Retrospective evaluation of the diets in the Cornell Net Carbohydrate and Protein System (Version 6.1) was conducted to determine ME-allowable milk and MP-allowable milk. Although ME-allowable milk increased with increasing dietary SFA (23.1, 24.3, and 25.4 kg/d, respectively), MP-allowable milk decreased slightly (26.1, 25.5, and 24.8 kg/d for SFA0, SFA1.5, and SFA3.0, respectively). Thus, milk production for cows fed 3.0% SFA was likely limited by MP. These results suggest that supplemental fat improves milk production in heat-stressed cows, as long as MP is adequate.

Milk fat levels are frequently low during the warm summer months (Kadzere et al., 2002). In our experiment, milk fat content and yield was increased for cows fed supplemental SFA (Table 3). This agrees with some studies (Skaar et al., 1989; Knapp and Grummer, 1991), but contradicts other observations (Drackley et al., 2003; Warntjes et al., 2008). The data suggest that milk fat levels increase when cows are fed a diet with supplemental saturated fats in tie-stall housing during heat stress (Skaar et al., 1989; Knapp and Grummer, 1991; current experiment). However, when cows are fed a diet with supplemental unsaturated fats (Drackley et al., 2003) or are housed in freestalls under commercial conditions

(Warntjes et al., 2008), where feeding behavior may include fewer larger meals during heat stress, milk fat levels are not improved with supplemental fat.

Because of the increased milk fat content in the current experiment, cows fed SFA had a 3-kg increase in SCM yield (Table 3). This is in agreement with results of other researchers (Moody et al., 1967; Skaar et al., 1989; Knapp and Grummer, 1991), who reported that feeding additional fat increased FCM production in heat-stressed cows.

Feed intake in lactating cows begins to decline at ambient temperatures of 25 to 26°C and decreases more rapidly above 30°C; at 40°C DMI may decline by as much as 40% (NRC, 1989). In the current experiment, we did not have a thermal neutral group of cows with which to compare DMI, but both environmental conditions and body temperature indices suggest that feed intake was probably depressed. Although DMI is decreased with high levels of some supplemental fats (i.e., calcium salts of unsaturated fatty acids and oilseeds), saturated fats and triglyceride have less or no effect on feed intake (Allen, 2000). Because of differences in dietary energy content, cows on both SFA dietary treatments in this study consumed more daily energy.

Cows fed SFA had improved production efficiency measured as total solids yield/DMI and SCM/NE_L intake relative to controls. This improvement was due to the increased milk and milk fat production with increasing levels of SFA. These data are in agreement with those of Chan et al. (1997). Feeding dietary SFA improved the efficiency of producing milk solids, which could be of economic importance.

Despite no difference in gross energy measurements (BCS, BW, and EB), cows fed 3.0% SFA had slightly reduced plasma NEFA levels compared with cows fed 0% SFA. Blood metabolites are more sensitive indicators of physiological changes than BCS or calculated EB. These data indicate that cows fed the higher SFA level may have been in an improved energy status. The effects of feeding supplemental fat to heat-stressed cows on circulating blood metabolites are not well understood. Increased NEFA concentrations were reported for heat-

stressed cows fed 3% supplemental fat as choice white grease (Drackley et al., 2003), but this is likely due to an increased level of unsaturated fatty acids because unsaturated fatty acids are oxidized to a greater extent than saturated fatty acids. Concentrations of NEFA have been reported to be similar (Harvatine and Allen, 2006) or greater (Harvatine and Allen, 2005; Relling and Reynolds, 2007) in mid-lactation dairy cows fed diets with supplemental unsaturated fatty acids compared with saturated fatty acids.

CONCLUSIONS

Cows in this experiment were heat stressed as indicated by THI and body temperature indices. Feeding supplemental SFA during heat stress decreased body temperatures during the hottest part of the day and increased milk yield, SCM yield, and milk fat content and yield. This demonstrates the remarkable amount of metabolic heat that is saved by energetically replacing fermentable carbohydrates with supplemental SFA. Whether or not the increased production was the result of the improved body temperature or independent of the thermal load is of interest.

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