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Effects of encapsulated niacin on evaporative heat loss and body temperature in moderately heat-stressed lactating Holstein cows

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ABSTRACT

Twelve multiparous Holstein cows (145 ± 9 d in milk) were randomly assigned to receive either 0 g/d of encapsulated niacin (control diet; C) or 12 g/d of encapsulated niacin (NI) and were exposed to thermoneutral (TN; 7 d) or heat stress (HS; 7 d) conditions in climate-controlled chambers. The temperature-humidity index during TN conditions never exceeded 72, whereas HS conditions consisted of a circadian temperature range in which the temperature-humidity index exceeded 72 for 12 h/d. Measures of thermal status obtained 4 times/d included respiration rate (RR); rectal temperature; surface temperature of both shaved and unshaved areas at the rump, shoulder, and tail head; vaginal temperature; and evaporative heat loss (EVHL) of the shoulder shaved and unshaved areas. Cows fed NI had increased free plasma niacin concentrations in both the TN and HS periods (1.70 vs. 1.47 ± 0.17 μg/mL). Milk yield did not differ between dietary groups or periods. Dry matter intake was not affected by NI, but decreased (3%) for both C and NI treatments during HS. Water intake was increased during HS in both treatments (C: 40.4 vs. 57.7 ± 0.8 L/d for TN and HS, respectively; NI: 52.7 vs. 57.7 ± 0.8 L/d for TN and HS, respectively). Average EVHL for shaved and unshaved skin for C and NI treatments was higher during HS (90.1 vs. 108.1 g/m^2 per hour) than TN (20.7 vs. 15.7 ± 4.9 g/m^2 per hour). Between 1000 and 1600 h, mean EVHL for shaved and unshaved areas for NI fed cows was higher than for C fed cows (106.9 vs. 94.4 ± 4.9 g/m^2 per hour). The NI fed cows had decreased rectal temperatures during HS compared with the C fed cows (38.17 vs. 38.34 ± 0.07°C) and had lower vaginal temperatures (38.0 vs. 38.4 ± 0.02°C). Calculated metabolic rate decreased during HS regardless of diet (50.25 and 49.70 ± 0.48 kcal/kg of body weight per day for TN and HS, respectively). Feeding NI increased free plasma NI levels, increased EVHL during peak thermal load, and was associated with a small but detectable reduction in rectal and vaginal temperatures in lactating dairy cows experiencing a mild thermal load.

Key words: dairy cow, heat stress, encapsulated niacin

INTRODUCTION

During warm summer months milk production can decrease between 10 and 35%. Estimated annual cost of summer heat stress to the United States dairy industry is $900 million (St. Pierre et al., 2003). The reduction in milk yield is a result of a decline in feed intake in heat-stressed cows as well as alterations in endocrine profiles and energy metabolism (Baumgard and Rhoads, 2007) and other unidentified factors (Collier et al., 2008). Increasing heat dissipation, the transfer of body heat from the core to the surface and then to the environment, via enhanced peripheral vasomotor function and evaporative heat loss may alleviate some of the decrease in DMI and thus increase milk production.

Niacin, nicotinic acid, or vitamin B_3 induced skin vasodilatation and increased heat loss at the periphery (Di Costanzo et al., 1997). The vasodilatory effects of niacin are the result of prostaglandin D (**PGD**) produced by epidermal Langerhans cells (Benyó et al., 2006; Maciejewski-Lenoir et al., 2006) acting on vascular endothelial PGD_2 receptors (Cheng et al., 2006). Increased skin blood flow was associated with increased sweating rate and inhibiting blood flow by inhibiting nitric oxide synthase, reducing sweating rate during exercise in humans (Welch et al., 2009). Skin temperatures decreased during periods of mild to severe heat stress in cows supplemented with 12, 24, or 36 g of raw niacin/d (Di Costanzo et al., 1997). This may have been associated with increased sweating and evaporative heat loss from skin surface. Past research evaluating niacin supplementation during heat stress used raw niacin, which would largely be metabolized by rumen microbes (Campbell et al., 1994). Previous research (Miller et al., 1986; Zinn et al., 1987; Santschi et al., 2005) demonstrated that very little (3–10%) niacin or nicotinamide escapes ruminal degradation. This extensive degradation by rumen microbes is the reason that relatively large doses of niacin were used in

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previous studies (12–36 g of niacin/d; Di Costanzo et al., 1997).

Encapsulation technology can dramatically increase the bioavailability of compounds to the small intestine, and lipid encapsulation was used for many years to coat and protect bioactive substances from rumen degradation. For example, advances in coating technology were used to protect choline. Kung et al. (2003) reported a high level (>70%) of choline protection in vitro, and Deuchler et al. (1998) observed increased milk choline levels when supplementing lipid-encapsulated choline to dairy cows. Using the same coating technology, a niacin product was developed that protects niacin from rumen degradation (>90%; Balchem Corp., New Hampton, NY; personal communication). The effects of feeding encapsulated niacin during thermal stress have not been evaluated, but we speculate that if niacin is rumen protected, then more would be intestinally bioavailable and produce a greater vasodilatory response. The hypothesis was that this would then lead to improved heat loss in cattle fed encapsulated niacin. A dose of 12 g/d of Niashure (Balchem Corp.) was chosen to match the lowest dose of the Di Costanzo et al. (1997) study. They used unprotected niacin.

Study objectives were 1) to determine whether supplementing encapsulated niacin at a dose of 12 g/d to lactating dairy cows increased free plasma niacin concentrations and 2) to determine whether niacin supplementation altered evaporative heat loss and measures of body temperature in lactating cows experiencing moderate thermal stress.

MATERIALS AND METHODS

Animals

Twelve multiparous Holstein cows producing 31 ± 4.75 kg of milk/d and balanced for parity (second and third lactation) and stage of lactation (145 ± 9 DIM) were housed in individual tie stalls in 1 of 2 environmentally controlled rooms in the William Parker Agricultural Research Center at the University of Arizona (Tucson). After 4 d of chamber adjustment, cows were exposed to a thermoneutral environment [**TN**; temperature-humidity index (**THI**) <72 for 24 h/d; Figure 1] condition, which lasted for 7 d (period 1). After the TN condition, cows were exposed to heat stress (**HS**) conditions that lasted for 7 d (period 2). The HS environment was a cyclical, moderate thermal stress (THI >72 for 12 of 24 h/d; Figure 1). Relative humidity was held constant at 18% during both periods and THI changes were achieved via controlled ambient temperature alterations. At the beginning of period 1, 6 cows (3 in each room) were randomly assigned to individually

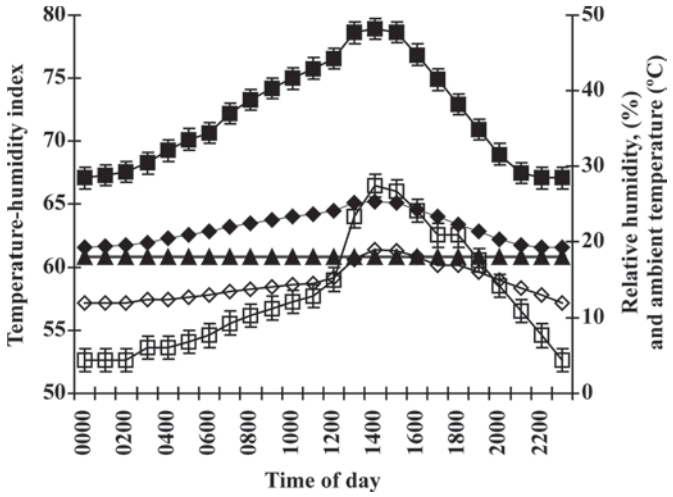

Figure 1. The 24 circadian temperature-humidity index patterns and SEM for period 1 (thermoneutral; □) and period 2 (heat stress; ■), and ambient temperature (°C) for period 1 (thermoneutral; ◊) and period 2 (heat stress; ♦). Relative humidity (▲) was kept constant at 18% for both period 1 and 2.

receive either 0 g/d of encapsulated niacin (control diet; **C**) or 12 g/d of an encapsulated niacin product (**NI**; Niashure), and all cows remained on dietary treatment until the end of period 2. The dose selected for this study (12 g/d) was chosen to overlap with the lowest dose of Di Costanzo et al. (1997). The NI product was 65% niacin and provided 7.8 g of niacin/d per cow. The NI dose was split and was top-dressed by suspending it in molasses (50 mL), which was mixed into the top 50% of the feed at each feeding. Milk yields were measured twice daily and sampled once daily in the morning for composition. Component analysis was conducted at Arizona DHIA (Tempe, AZ). Milk fat, protein, and lactose were analyzed using AOAC-approved infrared analysis (AOAC, 2007), and SCC was analyzed using AOAC-approved cell-staining techniques (AOAC, 2007). The International Dairy Federation and FDA certified all equipment used in the analyses. Milk yield was recorded at each milking and combined for daily milk yields. Cumulative water intake was recorded daily. Cows were fed a diet consisting primarily of alfalfa hay and steam-flaked corn balanced to meet or exceed nutrient requirements (Table 1; NRC, 2001) twice daily and refusals were measured daily.

Animal Measurements

All body temperature measurements except vaginal temperatures were recorded 4 times/d (0800, 1000, 1400, and 1600 h). Surface temperature (**ST**) of both shaved (electric clippers without any prior washing of the hair coat) and unshaved areas were obtained at the

Table 1. Ingredients and chemical composition of diets[1]

Item	% of DM
Alfalfa hay	54.9
Corn (steam-flaked)	15.9
Barley	15.9
Whole cotton seed	8.7
Supplement RS-1299[2]	2.6
Maxxer[3]	1.5
Amino Plus[4]	0.5

[1]Diet DM averaged 54%.

[2]Dairy Nutrition Systems (Tempe, AZ); contained 1.14% fat, 10.42% Ca, 4.49% P, 3.80% Mg, 0.49% S, 0.19% K, 15.83% Na, 7.52% Cl, 2,029.06 mg/kg of Zn, 1,991.82 mg/kg of Mn, 974.24 mg/kg of Fe, 583.45 mg/kg of Cu, 67.86 mg/kg of Co, 12.28 mg/kg of Se, 6.81 mg/kg of Mo, 43.68 mg/kg of I, 304.9 IU/g of vitamin A, 30.2 IU/g of vitamin D, and 1.0 IU/g of vitamin E.

[3]Calcium salts of palm oil (Tarome Inc., Eloy, AZ).

[4]Soybean-based supplement, 51.7% CP (Ag Processing Corp., Hastings, NE).

rump, shoulder, and tail head using an infrared temperature gun (RayngerMX model Ray MX4PU, Raytek Corp., Santa Cruz, CA). Rectal temperatures were obtained using a YSI rectal thermometer (Yellow Springs Instruments, Yellow Springs, OH). Temperature loggers (ibutton thermochrons, Maxim, Dallas, TX) were used to record vaginal temperature circadian patterns. The manufacturer reports a measurable range of 15 to 46°C measuring 0.125°C increments with ±1°C accuracy. The temperature loggers were calibrated in our laboratory at 38.5 or 42.0°C and analyses indicated variability of ±0.70 and ±0.40°C at 38.5 and 42.0°C, respectively. The mean offset for each thermochron button was consistent from one calibration to the next and was subsequently used as a covariate when vaginal temperature measurements were analyzed. The calibrated ibuttons were attached to blank continuous intravaginal drug release devices (Pfizer Inc., New York, NY) and inserted into the vagina on d 4 and removed on d 7 of each period. Temperatures were recorded at 15-min intervals over the 3-d period. Respiration rates (**RR**) were obtained 4 times/d (0800, 1000, 1400, and 1600 h) by visually counting flank movements, and evaporative heat loss (**EVHL**) of the shoulder shaved and unshaved areas was measured 4 times/d using an evapometer (Delfin Technologies Ltd., Kuopio, Finland). This evapometer is a closed chamber measure of EVHL, which does not take into account any effects of wind speed and results in a lower estimate of EVHL than those taken with devices that include wind speed (Gebremedhin and Wu, 2001). The purpose of obtaining EVHL on both shaved and unshaved areas of the hair coat was to estimate the effect of hair coat on EVHL. Total stored heat was calculated using the following formula: body temperature, °C × specific heat of tissue (0.8°C) × BW, kg (Silanikove, 2000; Sawka and Castellani, 2007). Cows were weighed on d 1 of period 1 and 2 and 3 d post period 2. Average metabolic rate (basal metabolism plus milk energy) was calculated using the following formula: $70.5 \times (\text{BW, kg})^{0.734} + (\text{milk yield, kg} \times 750 \text{ kcal/kg})$ (Kibler and Brody, 1944).

Room Temperature Controls and Data Collection

Data loggers, hard-wired into each environmental room, continuously recorded ambient temperature and relative humidity at 15-min intervals each day using a computer-based program (PARC Control Coding, John R. Bauer LLC, Tucson, AZ). Temperature-humidity index was calculated using dry bulb temperature (Tdb**;** °F) and relative humidity (RH): $\text{Tdb} - [0.55 - (0.55 \times \text{RH}/100) \times (\text{Tdb} - 58)]$ (Buffington et al., 1981).

Free Plasma Niacin Concentrations

Blood samples were collected into heparinized tubes using coccygeal venipuncture from individual cows at 1200 h 1 d before period 1 and on d 1 and 7 of period 1 and 2. Plasma was harvested after centrifugation and stored at −20°C until used for analysis. Plasma harvested from blood samples obtained at 1200 h (1 d before period 1 and on d 1 and 7 of period 1 and 2, and d 3 following period 2) was divided into 2 aliquots and frozen at −20°C for later analysis of niacin concentrations using the VitaFast (R-Biopharm, Dharmstadt, Germany) niacin microbiological assay. Prior to analysis, plasma samples for each day were pooled across cows within treatment to provide a single plasma sample for analysis for treatment and control groups. The pooled plasma (1.0 mL) was added to a sterile 50-mL conical centrifuge tube (227261, Greiner Bio-One, Monroe, NC), and 20 mL of sterile 20 m*M* sodium citrate buffer (pH 4.5; C0909, Sigma Aldrich, St. Louis, MO) was added to the plasma and manually shaken. Taka diastase (300 mg; 86247, Sigma Aldrich) was added, shaken vigorously, and incubated for 1 h without light at 37°C. Following incubation, sterile double-distilled H_2O (19 mL) was added and samples were heated for 30 min in a water bath at 95°C and shaken well every 5 min. Following heating, tubes were chilled quickly to <30°C using an ice bath. The tubes were centrifuged and the supernatant was decanted into sterile tubes. Three separate 150-μL samples were pipetted into individual wells coated with *Lactobacillus plantarum* in a 96-well microtiter plate that was incubated in the dark for 48 h at 37°C. *Lactobacillus* growth was enhanced as media niacin concentration increased. The assay was read spectrophotometrically for turbidity at 610 to 630 nm. The sensitivity limit of the assay was 16 ng/mL and the standard curve ranged from 160 ng/mL to 1.60

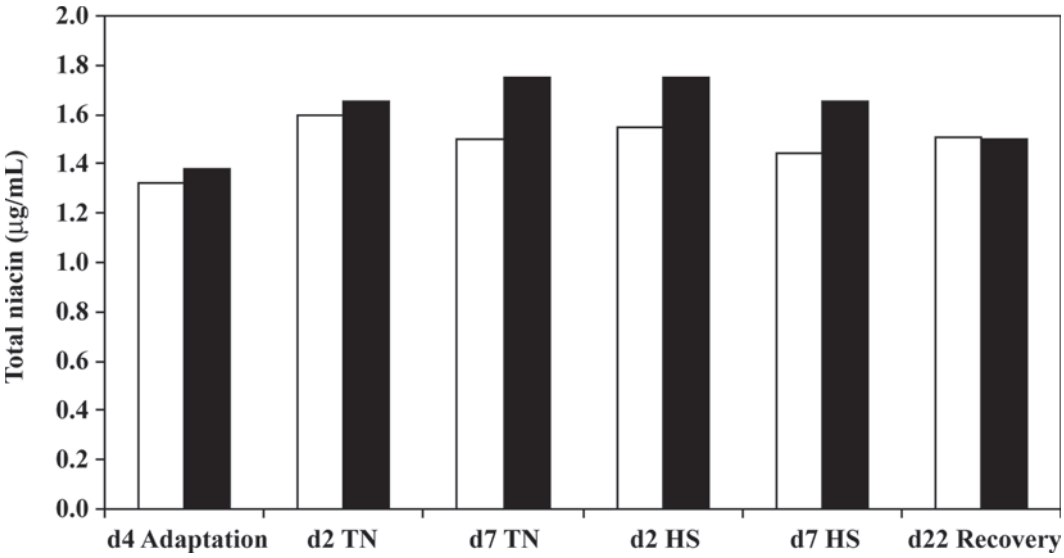

Figure 2. Plasma concentrations of free niacin in lactating Holstein cows supplemented with 0 g (white bars) or 12 g (black bars) of encapsulated niacin per day. SEM = 0.17. TN = thermoneutral; HS = heat stress.

μg/mL. All samples were run in a single assay with an intraassay coefficient of variation of <1.5%.

Statistics

Data were analyzed using ANOVA procedures of SAS (SAS Institute, 1999) using PROC MIXED and GLM procedures. Milk yields and DMI (recorded during the acclimation period and before dietary treatment or environment initiation) were included as a covariate in their respective analyses. Dependent variables tested were milk yield, DMI, ST (rump, shoulder, tail head, and shaved and unshaved areas), EVHL, RR, core body temperature, SNF, lactose, fat, protein, SCC percentages and yield, and water intake. The independent variables included treatment, day, parity, time of day, room, environment, and the respective interactions. In the case of the plasma niacin values, the samples for cows were pooled within treatment for each day, which prevented determination of any effects other than treatment and environment. The level of significance was set at $P < 0.05$ for all main effects and interactions and the LSMEANS test was conducted when significance was detected.

RESULTS

Prior to experiment initiation, pooled free plasma niacin levels did not differ for C and NI fed groups (1.32 vs. 1.38 μg/mL; Figure 2). By the end of the TN period, pooled plasma niacin concentrations were higher ($P < 0.03$) in NI fed cows compared with C fed cows (1.75 vs.1.50 μg/mL). Pooled plasma niacin remained increased ($P < 0.03$) in the NI fed cows compared with the C fed cows throughout HS (1.65 vs. 1.44 μg/mL). Free plasma niacin levels did not differ ($P > 0.05$) between dietary groups by 3 d following period 2.

Dry matter intake was not affected by diet, but decreased ($P < 0.05$) during HS (38.9 vs. 37.7 kg/d for C and NI fed cows; Table 2). During HS both C and NI fed cows had increased ($P < 0.01$) water intakes compared with TN (40.4 vs. 48.6 and 52.7 vs. 57.7 L/d, respectively; Table 2). Milk yield did not differ between dietary groups or environments (Table 2). Milk fat content did not differ between dietary groups ($P = 0.55$; Table 2); however, during HS both C and NI fed cows tended ($P = 0.06$) to have decreased milk fat levels compared with TN (3.94 vs. 3.77 and 4.0 vs. 3.51, respectively; Table 2). Milk protein content was lower ($P < 0.001$) for NI fed cows compared with C fed cows (2.84 vs. 2.93%; Table 2), but diet had no effect on milk protein yield. Both C and NI fed cows had increased ($P < 0.001$) milk protein percentage during HS (2.86 vs. 2.99 and 2.76 vs. 2.91%, respectively; Table 2), but milk protein yield did not differ between diets. Milk lactose percentage and lactose yield was unaffected by diet or period. Overall milk SNF content was lower ($P < 0.01$) for NI fed cows compared with C fed cows (8.44 vs. 8.55%; Table 2). Both diet groups had increased ($P < 0.001$) SNF percentages during HS compared with TN conditions (8.55 vs. 8.67 and 8.44 vs. 8.59% for C and NI fed cows, respectively), but neither diet nor period had an effect on milk SNF yield.

Surface temperatures obtained from the shoulder, rump, and tail head were unaffected by NI feeding, but were affected by removal of the hair coat. When the

Table 2. Effects of heat stress and encapsulated niacin on production variables in lactating Holstein cows[1]

	TN		HS		*P*-value			
Variable	C	NI	C	NI	Diet	Period	Diet × period	SEM
DMI (kg/d)	39.1	38.7	38.8	36.7	0.69	0.05	0.14	1.73
Water intake (L/d)	40.4	52.7	48.6	57.7	0.11	<0.01	0.45	0.77
Milk yield (kg/d)	29.3	30.5	29.4	29.6	0.17	0.35	0.25	0.38
Fat (%)	3.94	4.00	3.77	3.51	0.55	0.06	0.36	0.17
Milk fat yield (kg/d)	1.15	1.11	1.11	1.04	0.97	0.04	0.89	0.09
Protein (%)	2.86	2.76	2.99	2.91	<0.001	<0.001	0.77	0.02
Milk protein yield (kg/d)	0.83	0.84	0.88	0.86	0.71	0.30	0.19	0.03
Lactose (%)	4.68	4.66	4.69	4.69	0.66	0.062	0.75	0.03
Lactose yield (kg/d)	1.37	1.42	1.38	1.39	0.10	0.37	0.19	0.06
SNF (%)	8.55	8.44	8.67	8.59	<0.01	<0.001	0.71	0.02
SNF yield (kg/d)	2.51	2.57	2.54	2.54	0.82	0.97	0.89	0.06

[1]TN = thermoneutral (temperature-humidity index <72 for 24 h/d; HS = heat stress (temperature-humidity index >72 for 12 of 24 h/d); C = control (0 g of Niashure; Balchem Corp, New Hampton, NY); NI = treatment (12 g of Niashure).

hair coat was removed the mean skin temperature was higher (32.5 vs. 31.4°C ± 0.20 for shaved and unshaved, respectively; $P < 0.05$; data not shown). The difference between skin and hair coat temperature did not differ by environment (TN vs. HS; Table 3). All ST were higher in HS compared with TN (Table 3). Evaporative heat loss was measured on shaved and unshaved skin to determine the effect of hair coat. The presence of the hair coat reduced EVHL in both treatments, but there was no treatment by hair coat interaction (data not shown). The mean EVHL for the 4 daily measurements was lower in both groups during TN and increased during HS (18.2 vs. 98.9 ± 4.9; $P < 0.001$; Table 3). In addition to the effect of environment (TN vs. HS), there was an effect of time of day on EVHL measurements. Values were low in the morning and increased as environmental temperatures in the room increased in the afternoon hours ($P < 0.01$; Figure 3). The NI fed cows had higher mean EVHL for both shaved and unshaved areas measured during the HS period, but not during the TN period (Table 3). Furthermore, these differences became larger in measurements taken during peak thermal stress at 1400 h, producing a treatment by diet by time of day interaction ($P < 0.001$; data not shown). The EVHL for NI fed cows was higher ($P < 0.0001$) than for C fed cows in HS between 1000 and 1600 h (Figure 3), resulting in a 3-way interaction of diet by period by time of day. During the TN period, rectal temperature did not differ between diets (Table 3), but NI fed cows had lower mean vaginal temperatures than C fed cows during HS (38.0 vs. 38.4 ± 0.02°C; $P < 0.001$; Figure 4). The pattern of rectal (data not shown) and vaginal temperatures demonstrated increases in both measures of core body temperature during afternoon hours. Control and NI groups had higher RR during HS (31.6 vs. 52.7 ± 2.0 breaths/min; TN vs. HS; $P < 0.0001$; Table 3).

The effect of environment and dietary NI on estimated heat production and stored heat is shown in Table 4. Average stored body heat was not higher for NI fed cows compared with the C fed cows during both TN and HS (Table 4), but there were differences attributable to period. When calculated on a BW basis, there was a tendency toward a diet by environment interaction because stored heat tended ($P < 0.10$) to be lower during HS when cows were supplemented with NI (30.42 and 30.58 kcal/kg of BW for HS vs. 30.65 and 30.27 kcal/kg of BW for TN). The estimated metabolic rates of the 2 groups did not differ by diet, but were lower during HS compared with TN conditions (50.2 vs. 49.7 ± 0.48; Table 4; $P < 0.05$).

DISCUSSION

When free nicotinamide was supplemented to cattle its disappearance was almost complete before the duodenal cannula (Zinn et al., 1987; Santschi et al., 2005). Absorption through the ruminal wall is a plausible route of niacin uptake because when nicotinamide is supplemented, the levels of free niacin were increased but the extent was minimal (Santschi et al., 2005). These investigators reported that minimal niacin escaped ruminal degradation; therefore, the benefits reported when niacin was fed were likely related to the systemic effects of niacin that had been absorbed across the rumen or had diffused across the gastrointestinal wall before the duodenal cannula.

The plasma free niacin data from this study support the concept that encapsulation of niacin would improve rumen bypass and lead to increased blood niacin concentrations. The majority of niacin absorbed across the gut wall in cattle was rapidly incorporated and stored in red blood cells (Campbell et al., 1994), but there was measurable free niacin in blood. Recently, Niehoff et al.

Table 3. Effect of feeding encapsulated niacin on surface temperatures, evaporative heat loss, respiration rate, and rectal temperature in lactating Holstein cows[1]

	TN		HS		*P*-value			
Variable[2]	C	NI	C	NI	Diet	Period	Diet × period	SEM
Surface temperature (°C)								
Shoulder, shaved	31.3	30.9	34.3	34.1	0.62	<0.01	0.88	0.2
Shoulder, unshaved	29.9	29.6	33.4	33.6	0.32	<0.001	0.23	0.22
Rump, shaved	31.4	31.3	34.5	34.5	0.85	0.05	0.74	0.19
Rump, unshaved	30.4	30.3	33.8	33.7	0.92	<0.01	0.97	0.24
Tail head, shaved	30.5	30.7	33.4	33.7	0.18	<0.05	0.89	0.21
Tail head, unshaved	28.4	28.5	32.8	32.6	0.93	<0.001	0.65	0.29
Evaporative heat loss[3]								
Shaved (g/m^2 per h)	23.2	18.3	92.4	114.4	0.36	<0.001	0.001	4.90
Unshaved (g/m^2 per h)	18.2	13.1	87.2	101.7	0.36	<0.001	0.001	4.89
Respiration rate (bpm)[4]	30.6	32.5	50.8	54.5	0.14	<0.001	0.59	2.01
Rectal temperature (°C)	38.01	38.06	38.34	38.17	0.05	<0.001	0.07	0.07

[1]TN = thermoneutral (temperature-humidity index <72 for 24 h/d; HS = heat stress (temperature-humidity index >72 for 12 of 24 h/d); C = control (0 g of Niashure; Balchem Corp, New Hampton, NY); NI = treatment (12 g of Niashure).

[2]Variables represent mean for all 4 measurement times.

[3]Closed chamber evapometer.

[4]bpm = breaths/min.

(2009) reviewed studies using niacin supplementation in dairy cattle and reported a range of 1 to 5 μg/mL of free niacin in plasma. At the start of this study and before administration of dietary treatments, the plasma niacin concentration was approximately1.38 μg/mL and did not differ between groups subsequently given C or NI dietary treatments. Supplementing encapsulated niacin increased plasma levels of free niacin from 1.5 μg/mL in C fed cows to 1.75 μg/mL in NI fed cows. Thus, feeding encapsulated niacin increased plasma concentrations of niacin while cows were being supplemented and values reported were similar to other laboratories (Niehoff et al., 2009). Finally, plasma niacin concentration levels in NI fed cows returned to presupplementation values by 3 d postsupplementation (1.51 vs.1.50 μg/mL). Thus, feeding encapsulated niacin at a dose of 12 g/d per cow increased free plasma niacin concentration. It is possible that measuring total blood niacin would provide greater differences in niacin concentrations between NI and C animals because the majority of niacin in blood was stored in red blood cells (Campbell et al., 1994).

No previous studies evaluated use of supplementary dietary encapsulated niacin on evaporative heat loss and heat storage in lactating dairy cows. Given the effects of niacin on cutaneous blood flow one might predict an increase in heat loss in niacin supplemented cows subjected to heat stress. However, an increase in skin temperature in NI fed cows was not detected, which would have supported an increase in skin blood flow. Previous studies in HS models have involved supplementing niacin in a raw form that is not encapsulated and have resulted in inconclusive results. Environments implemented during this study were considered thermoneutral and mild to moderate HS. Vaginal temperatures during TN did not differ between C and NI fed cows (data not shown). However, the vaginal temperature in C fed cows was 0.5°C higher than NI fed cows during HS over the 3-d period measured (Figure 4). Although the HS environment altered rectal temperature and RR, there was no apparent effect on milk yield of the cows. Removal of the hair coat increased EVHL in C and NI groups ($P < 0.01$; Table 3; analysis not shown). This is likely attributable to increased airflow over the skin surface in shaved areas because of hair removal (Gebremedhin and Wu, 2001). Additionally, removal of the hair coat would alter the vapor pressure gradient

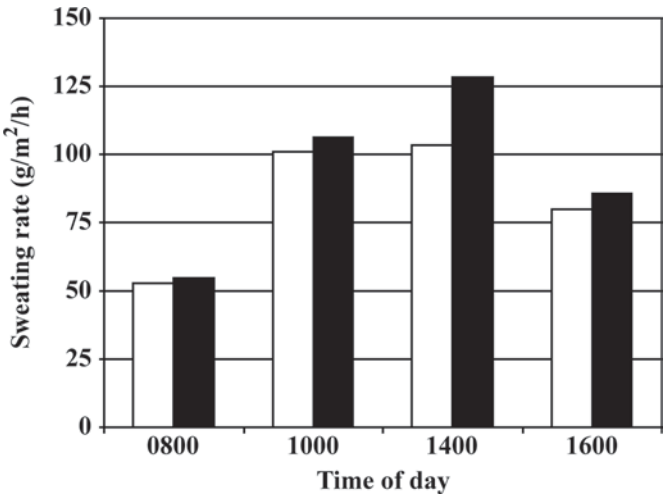

Figure 3. Effect of temperature-humidity index (THI) on mean evaporative heat loss in control (white bars) and niacin-fed (black bars) cattle at 0800, 1000, 1400, and 1600 h during heat stress. THI values in boxes represent THI at time of measurement (THI at 0800 h = 73.4; THI at 1000 h = 75.1; THI at 1400 h = 78.9; and THI at 1600 h = 77.5; SEM = 6.6).

Table 4. Effects of feeding encapsulated niacin on estimated metabolic rate, stored heat, body temperature, and evaporative heat loss per hour[1]

	TN		HS		*P*-value			
Variable	C	NI	C	NI	Diet	Period	Diet × period	SEM
Average BW[2] (kg)	597	599	596	605	—	—	—	
Average surface area[2] (m^2)	5.54	5.58			—	—	—	
Metabolic rate[3] (kcal/d)	29,533	30,618	29,725	29,963	0.15	<0.05	0.81	286.6
Metabolic rate (kcal/kg of BW)	49.72	50.78	49.87	49.53	0.05	<0.05	0.81	0.48
Total stored heat[4] (kcal)	18,073	18,361	18,223	18,405	0.92	<0.0001	<0.10	458.2
Total stored heat (kcal/kg of BW)	30.27	30.65	30.58	30.42	0.92	<0.0001	<0.10	0.8
Mean body temperature[5] (°C)	35.7	35.7	36.9	36.8	0.45	<0.0001	0.43	0.1
Evaporative heat loss[6] (kcal/h)								
Shaved	74.6	59.2	296.9	370.2	0.11	<0.001	<0.10	22.0
Unshaved	58.8	43.0	280.2	329.1	0.05	<0.001	<0.10	21.06

[1]TN = thermoneutral (temperature-humidity index <72 for 24 h/d; HS = heat stress (temperature-humidity index >72 for 12 of 24 h/d); C = control (0 g of Niashure; Balchem Corp, New Hampton, NY); NI = treatment (12 g of Niashure).

[2]Over entire trial, not separated by period.

[3]Calculated as 70.5 (BW, kg)$^{0.734}$ + (milk yield, kg × 750 kcal/kg).

[4]Calculated as + body temperature, °C × specific heat of tissue (0.8) × BW, kg.

[5]Calculated as 0.33 × temperature of skin, °C + 0.67 × rectal temperature, °C.

[6]Average for all 4 measurement times (sweating rate/h × surface area × 580 cal/g of sweat).

because hair traps moisture. The additional increases in EVHL in HS in NI fed cows appears attributable to increased sweating rate because it was most apparent in unshaved areas of the hair coat. This suggests that one effect of NI feeding during HS is increased sweat gland activity. The average estimated difference in stored heat between C and NI cows during HS was approximately 182 kcal (Table 4). When multiplying the difference in EVHL between C and NI cows found in Table 4 by the number of hours recordings were made (8 h), a difference in EVHL between NI and C fed cows was 586.4 kcal for shaved and 391.2 kcal for unshaved areas of the hair coat. Thus, the estimated difference in EVHL approximates the difference in stored heat between the groups. The closed chamber estimates of EVHL obtained do not account for any effects of wind speed and were uniformly lower than estimates taken when wind speed was included (Gebremedhin and Wu, 2001). Vaginal probes were inserted during d 4 to 7 of each period to record circadian patterns of vaginal temperatures. During TN there were no treatment differences in core body temperature patterns; however, during HS, NI fed cows had lower vaginal temperatures than C fed cows (Figure 4). This is further supported by the increased EVHL in NI fed cows. The vasodilatory effects of niacin involve PGD production by epidermal Langerhans cells (Benyó et al., 2006; Maciejewski-Lenoir et al., 2006) acting through vascular endothelial PGD_2 receptors (Cheng et al., 2006) to increase vasodilation. Niacin induced vasodilation of the skin in humans (Gille et al., 2008). This mechanism was associated with the reduction in core body temperature and increases in EVHL during HS recorded. Increasing the surface temperature by increasing peripheral blood flow might increase evaporative heat loss without affecting sweating rate (Gebremedhin and Wu, 2001) in addition to increasing radiant and convective heat loss. Regardless, the net effect would increase both sensible and insensible forms of heat loss. Thus, feeding NI was associated with increased heat loss and lower body temperatures in mild to moderate HS. But, the cause of the increased EVHL (direct via increased sweating rate or indirect via increased surface temperature) in NI fed cows remains to be elucidated.

There were no differences in DMI between dietary treatments, which supports previous nicotinic acid or nicotinamide research (Kung et al., 1980; Jaster and

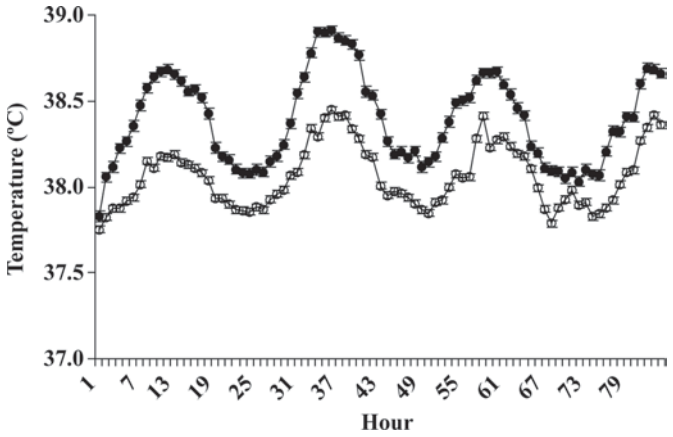

Figure 4. Pattern of vaginal temperatures at 1-h intervals of lactating Holstein cows supplemented with 0 g (●) or 12 g (○) of encapsulated niacin per day during d 4 to 7 of heat stress. The SEM derived from the pooled vaginal temperatures was 0.02. Treatments differ at $P < 0.001$.

Ward, 1990). As expected, HS decreased DMI in C and NI fed cows. Milk yield differences existed before study initiation and were unexpected because the groups were balanced for parity and yield during treatment assignment. As stated earlier, supplementing lactating dairy cows with raw niacin resulted in inconsistent results, where some have found increases (Muller et al., 1986; Drackley et al., 1998) in milk yield and others reported no difference (Di Costanzo et al., 1997; Madison-Anderson et al., 1997). Although there were clear signs of increased heat load in HS, such as increased body temperature and RR and reduced feed intake, there was no change in milk yield in the 2 groups. Milk component differences found were small and were not associated with differences in milk component yields (Table 2).

CONCLUSIONS

The supplementation of encapsulated niacin to mildly thermally stressed lactating dairy cows increased EVHL and decreased vaginal temperatures. The number of cows (12) used precluded any serious analysis of milk production responses such as Muller et al. (1986), which is the only large-scale study reported to date with 240 animals. Further studies evaluating the effect of encapsulated niacin on lactating dairy cows during thermal stress are warranted.

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