Feeding Strategies for High-Producing Dairy Cows During Periods of Elevated Heat and Humidity

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Summary

A re-evaluation of the temperature humidity index **(THI)** confirmed that current THI values underestimate the severity of heat stress levels. Previously, a THI equal to or greater than 72 has been used to define onset of heat stress, but our research demonstrated that a THI greater than or equal to 68 is low enough to cause adverse affects when cows suffer from heat stress. Furthermore, we were able to demonstrate that when average THI is 68 or higher, the milk yield loss becomes highly significant after 17 hours of exposure.

Supplementation of lactating dairy cows with encapsulated niacin proved to alleviate some affects of heat stress during acute thermal stress. This was observed through increased evaporative heat loss, increased water intake to support the increased sweating rate, and decreased rectal and core temperatures. Milk production was not affected by the supplementation of encapsulated niacin.

Introduction

During warm summer months, milk production can decrease between 10 to 35%, and this is a costly issue in the dairy industry (St. Pierre et al., 2003). The reduced milk yield is a result of increased body temperature induced-decline in feed intake, as well as alterations in endocrine profiles, energy metabolism (Baumgard and Rhoads, 2007) and other unidentified factors (Collier et al., 2008). The economic impact of heat stress on the U.S. dairy industry has averaged annual losses of over $800 million as a result of reduced performance and increased incidence of disease (St. Pierre et al., 2003). In unusually warm summers, these costs rapidly increase. For example, during the summer of 2006 a 2-week heat wave in California caused an estimated $1 billion loss in production and animals.

When the effective environmental temperature exceeds the thermal zone of comfort, or thermo-neutral zone, cows experience heat stress (Armstrong et al., 1993). A cow's thermo-neutral zone is dependent upon physiological status and level of production. Since average milk yield in US dairy cows has doubled since the 1950s, the thermoneutral zone has shifted downward as cows become more heat sensitive and cold tolerant (Collier et al., 2004). Environmental factors that influence the effective environment around the animal include relative humidity, velocity of ambient air, degree of solar radiation, thermal radiation, and moisture loss (NRC, 1981; St. Pierre et al., 2003).

Strategies to Alleviate Heat Stress

Temperature Humidity Index

The current Temperature Humidity Index (THI = tdb + $0.36t_{dp}$ + 41.5, where tdb = dry bulb temperature, ºC and t_{dp} = dew point temperature, ºC), originally developed by Thom (1958) and

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extended to cattle by Berry et al. (1964), is currently used to estimate cooling requirements of dairy cattle in order to improve the efficiency of management strategies to alleviate heat stress. The THI values were categorized into mild, moderate, and severe stress levels for cattle by the Livestock Conservation Institute (Armstrong, 1994; Whittier, 1993). Previous studies have shown that milk production can be reduced significantly (10 to 35%) when the THI exceeds 72 (Thatcher et al., 1974; Schneider et al., 1984). However, as pointed out by Berman (2005) the supporting data for these designations are not published. During these evaluations, the index was a result of retrospective analysis of studies conducted at the University of Missouri in the 1950s and early 1960s on a total of 56 cows with milk yield averaging 34 lb/day (range 6 to 70 lb/day). In contrast, average production per cow in the US is presently over 65 lb/day with many cows producing above 110 lb/day at peak lactation. Escalating milk yield increases sensitivity of cattle to thermal stress and reduces the 'threshold temperature' at which milk losses occur (Berman, 2005). This is because metabolic heat production increases with production level of the cow. Several lines of evidence indicate that THI predictions of milk yield losses to varying THI values are currently underestimating the severity of heat stress on physiological responses in Holstein cattle (Linvill and Pardue, 1992; Holter et al., 1996; Ravagnolo and Miztal, 2000; West et al., 2003; Berman, 2005). Again, this is due in part to the fact that current high yielding cattle are producing more heat (Collier et al. 2005). An example of the increased heat production from cows producing 41 and 70 lb/day of milk was 27.3 and 48.5%, respectively, higher than non-lactating cows (Purwanto et al., 1990). In fact, Berman (2005) indicated that increasing milk production from 77 to 99 lb/day decreased threshold temperature for heat stress by 5ºC (41ºF). Thus, THI predictions of environmental effects on milk yield presently underestimate the magnitude of thermal stress on contemporary Holstein cattle. Furthermore, the work by Berry et al. (1964) did not take into account radiant heat load or convection effects. The vast majority of cattle today are housed under some type of shade structure during warm summer months, and although this greatly reduces solar heat load, there is still a radiant heat load on animals emanating from the metal roof. Berman (2005) estimated that the typical shade structure in Israel adds an additional 3ºC (37ºF) to the effective ambient temperature surrounding animals. In addition, there are varying convection levels under shade structures, depending on whether fans are used as part of the cooling management system.

In the application of the current THI values, the other factor to consider is the management time interval. The time interval involved in the original THI predictions by Berry et al. (1964) was 2 weeks. In other words, the milk yield response to a given THI was the average yield in the second week at a given environmental heat load. Therefore, this time lag is fiscally unacceptable as dairy producers need to immediately know what level/extent of cooling is required in order to prevent present and future production losses. Collier et al (1981) and Spiers and et al. (2004) indicated that effects of a given temperature on milk yield were maximal between 24 and 48 hrs following a stress. Additionally, it has been reported that ambient weather conditions 2 days prior to milk yield measurement had the greatest correlation to reductions in production and dry matter **(DM)** intake (West et al., 2003). Furthermore, Linvill and Pardue (1992) indicated that the total number of hours when THI exceeded 72 or 80 over a 4-day interval had the highest correlation with milk yield. Collectively, these results demonstrate that current THI values for lactating dairy cows underestimate the size of the thermal load, as well as the impact of given thermal loads on animal productivity and have an inappropriate time interval associated with cooling management decisions. Practically, if producers can avoid an acute (i.e., 48 hr) decline in production, this will probably result in maintaining lactation persistency (i.e., 2 weeks later). Specifically, the time frame for utilizing THI values to reduce milk yield losses needs to be minimized, and it is necessary to re-evaluate the THI for high-producing dairy cows. A final component of the current THI is the pattern of stress application. In the original work by Berry et al. (1964), cows were exposed to given THI conditions continuously (no daily fluctuations) for the entire 2-week period. This is not what occurs under natural/practical management conditions with daily circadian patterns (rise and fall) during a normal 24-hour day. Examining the average, minimum, maximum, and hours above a certain THI are necessary; past research has indicated a high correlation between minimum THI and a reduction in feed intake when compared with maximum THI (Holter et al., 1996). Ravagnolo and Mitzal (2000) evaluated test day yields and found a decrease of 0.44 lb milk per unit increase in THI above 72 when THI was composed of maximum temperature and minimum humidity. The effects of radiant heat load can be evaluated using the Black Globe Humidity Index ($BGHI = t_{bg} + 0.36t_{dp} + 41.5$, where t_{bg} = black globe temperature ºC and t_{dp} = dew point temperature, ºC), developed by Buffington et al. (1981). These investigators demonstrated that BGHI had a higher correlation to rectal temperature increases and milk yield decreases than THI. They also pointed out that the correlation of BGHI to milk yield was greater ($r^2 = 0.36$) under conditions of high solar radiation (no shade) than under a shade structure ($r^2 = 0.23$). However, milk yields in this study were also low (average 33 lb/cow). Therefore, correlations of BGHI to milk yield under shade structures might be higher with higher producing dairy cows (they are more sensitive to increased heat loads).

University of Arizona - New THI

Materials and Methods

The data analyzed in our project was obtained from 8 different studies during the course of 3 years. One hundred multiparous Holstein cows were housed in individual tie stalls in one of two environmentally controlled chambers in the William Parker Agricultural Research Center at the University of Arizona. The University of Arizona's Institute of Animal Care and Use Committee approved all protocols and use of animals. Temperature Humidity Index was calculated using dry bulb temperature ($\mathbf{T_{db}}$, °F) and relative humidity (**RH**), ($T_{db}-(0.55-(0.55*RH/100)*(T_{db}-58)$; Buffington et al., 1981). Black globe humidity index was calculated by using black globe temperature (T_{bg}, °C) and RH (Buffington et al., 1981).

Groups 1 to 4

Forty-eight multiparous lactating Holstein cows were balanced for parity and stage of lactation and assigned to an incomplete crossover design involving 2 levels of radiant heat load, 2 levels of dry bulb temperature, and 2 levels of humidity. These parameters were then combined to produce 8 experimental environments. Each of these 8 environments have a range of dry bulb temperature, radiant energy, RH, and THI values mimicking a possible 24-hour period under shade structures during summer months in the southern part of the United States. Cows were housed at the University of Arizona, William J. Parker Research Complex, in 2 environmental chambers, with only one room capable of producing radiant heat load. Six cows were housed in each environmental chamber and each group consisted of 12 cows; therefore, 4 groups of animals (n=12) were brought to the facilities at separate times in order to reproduce 8 environments. Each group of animals experienced a minimum of 2 and a maximum of 3 environments over a 22-day period. Animals entering the facility were provided 7 days to acclimate to the chambers in a thermal neutral environment (Environment #3). Followed by a 4 day experimental environment, then cow's switched environmental chambers and were provided 7 days to acclimate to the new chamber in a thermal neutral environment (Environment #3). After 7 days, cows experienced the opposite experimental environment for 4 days. Cows were milked and fed twice daily, with orts measured once a day prior to the morning milking. During adjustment periods, respiration rates **(RR)**, surface temperatures **(ST)**, evaporative heat loss **(EVHL)**, rectal temperatures **(RT)**, and heart rate **(HR)** were measured. Skin temperatures and sweating rates were measured from the shoulder, ribs, and rump of the animal twice a day (0500 and 1700 hour). These same heat parameters were measured 4 times a day (0500, 1000, 1400, and 1700 hour) during the 4 day experimental periods. On the third day of each 4 day period, a 24 hour recording of these same observations were made every hour on the hour. Skin temperatures were measured with an infrared temperature gun (Raynger® MX™, model RayMX4PU; Raytek C, Santa Cruz, CA). Rectal temperatures were measured using a digital thermometer (GLA M700 Digital Thermometer, San Luis Obispo, CA). Respiration rates were obtained by visually counting flank movements during a 15 sec interval and multiplying by 4 and evaporative heat loss was measured using an evapometer (Delfin Technologies, LTD., Finland). Heart rate was measured by cardiac auscultation. Environmental parameters recorded hourly and used for calculations of BGHI and THI are ambient temperature (T_{db}), RH, black globe temperature (T_{bg}), and radiant energy.

Group 5

Twelve multiparous mid lactation cows were assigned to one of two studies in January or June of 2004. Animals were balanced for parity and assigned to one of two environmental chambers at the University of Arizona, William J. Parker Research Complex. Environmental treatments consisted of one thermal neutral environment (46 to 59°F, 8 to 40% humidity) and 2 heat stressed environments: 1) 86 to 104°F, 8 to 40% humidity and 2) the same heat stress conditions with the additional 4 hours of solar radiation at 600 watts/hour/m^2 from 1100 to 1500 hour). Animals were provided 7 days to adjust to the facilities and then experienced 3 14-day periods in an incomplete, crossover design. Solar lamps were only available in one of the environmental chamber rooms; cows had to switch rooms prior to the third period so that all animals experienced all environments. Once animals switched rooms, they were provided 7 days to re-adjust to their new environmental chamber prior to period 3. Cows were milked 2 times a day (0600 and 1800 hour) and milk weights recorded at each milking. Animals were fed a TMR 2 times a day (0700 and 1700 hour) and orts were weighed and recorded prior to the morning feeding.

Heat parameters were measured bihourly on day 6 of each period. Skin temperatures were measured with an infrared temperature gun on the right and left sides of the animal on the middle of the rump and loin (Raynger® MX™, model RayMX4PU, Raytek C, Santa Cruz, CA). Rectal temperatures were measured using a digital thermometer (GLA M700 Digital Thermometer, San Luis Obispo, CA). Respiration rates were obtained by visually counting flank movements during a 15 sec interval and multiplying by 4, and evaporative heat loss was measured using an evapometer (Delfin Technologies, LTD., Finland). Heart rate was measured by cardiac auscultation.

Group 6

A total of 12 lactating multiparous Holstein cows averaging 140 ± 13 days in milk **(DIM)** were assigned randomly to one of two environmental chambers at the William J. Parker Agricultural Research Complex at the University of Arizona. Cows were milked twice a day and recorded for daily milk yield. A total mixed ration was fed twice daily and weigh backs were measured once a day prior to the morning feeding. Dairy Nutrition Services (Chandler, AZ) formulated the TMR to meet or exceed energy requirements according to NRC, 2001. All studies were approved by the University of Arizona Institutional Animal Care and Use Committee. Cows were given 7 days to acclimate in the environmental chambers and both groups, regardless of treatment, were exposed to thermal neutral conditions (68°F, 20% humidity, THI = 64). Following acclimation, cows continued to experience the same thermal neutral conditions for an additional 9 days and allowed to eat ad libitum (Period 1; P1). Period 1 and period 2 (P2) were separated by 7 days, where cows remained in the same thermal neutral condition. During P2, cows in group 1 remained in the same thermal neutral condition, while cows in group 2 experienced heat stress **(HS)** and were fed ad libitum. In order to mimic daily variations, HS cyclical temperatures ranged from 85 to 102°F with humidity held constant at 20%; THI ranged from 73 to 82 daily. Respiration rate (RR), ST, and RT were measured and recorded 4 times daily (0600, 1000, 1400, and 1800 hour). Measuring RR was done by counting flank movements for 60 sec. On a shaved section on the shoulder of the cow, skin temperatures were measured with an infrared temperature gun (Raynger® MX™, model RayMX4PU, Raytek C, Santa Cruz, CA). Rectal temperatures were measured using a digital thermometer (GLA M700 Digital Thermometer, San Luis Obispo, CA).

Group 7

Ten lactating multiparous Holstein cows averaging 99.8 ± 20.2 DIM were randomly assigned to one of two environmental treatments over the course of 3 experimental periods. All animals were housed at the University of Arizona, William J. Parker Research Complex in tie-stall stanchions in the environmental chambers. Animals were exposed to 3 experimental periods, period 1 (P1), 7 days of thermal neutral conditions, period 2 (P2), 7 days of heat stress, and period 3 (P3), 7 days of heat stress; totaling 21 days to complete the entire study. Period 1 consisted of thermal neutral conditions (68°F, with humidity held constant at 20% with a 12- and 12-hour light and dark cycle). Period 2 and P3 environments consisted of heat stress with cyclical daily temperatures in order to mimic daily variations (ranging from 85 to 102°F with humidity being held at 20%, THI = 72.4 to 82.2, and with a 12- and 12- hour light and dark cycle). All cows were fed a total mixed ration three times a day (0500, 1200, and 1700 h) and orts were recorded once a day prior to the morning feeding. All cows were allowed to eat ad libitum. All cows were milked 2 times a day (0500 and 1700 hour), and yield was recorded at each milking.

Heat parameters, such as RR, ST (from the shoulder, rump, and tail head), and RT were measured 4 times a day (0600, 1000, 1400, and 1800 hour). Surface temperatures were measured using an infrared temperature gun (Raynger®MX™, model RayMX4PU, Raytek C, Santa Cruz, CA). Rectal temperatures were obtained using a standard digital thermometer (GLA 525/550 Hi-Performance Digital Thermometer, San Luis Obispo, CA).

Group 8

Eighteen second lactation Holstein cows averaging 89.2 (± 8.1) DIM were randomly assigned to an environmental chamber room into individual tie stalls located at the University of Arizona, William J. Parker Research Complex. The chamber rooms only house 6 cows at a time; therefore, the study was replicated 3 times and one cow was removed from the study due to temperament issues in the facilities. All cows were milked 2 times a day, and milk weights were recorded at each milking (0500 and 1700 hour). All cows were fed a TMR 2 times day at milking times, and orts were recorded prior to the morning feeding. Cows were housed at the University of Arizona dairy for 19 days prior to entering the environmental chambers. While at the dairy farm, cows received one of two dietary treatments: 1) Control diet with 0 g/ton Rumensin (Elanco Animal Health, Greenfield, IN), or 2) the control diet top dressed with Rumensin at 450 mg/cow/day. Once they entered the facility, they were provided 3 days to adjust; however, they continued on their dietary treatment. All cows, regardless of dietary treatment, experienced a constant thermal neutral environment (20% humidity, THI = 64, with a 14 hour light and 10 hour dark cycle) and allowed to eat ad libitum for 9 days (experimental period [**P**] 1). They were then given 2 days in the same thermal neutral environment prior to experiencing P2 (experimental period [**P**] 2), which consisted of cyclical temperatures (85 to 102°F with constant 20% humidity; THI $\geq$ 73, $\leq$ 82; and a 14 hour light and 10 hour dark cycle) and were fed ad libitum. This environment was made to replicate daily variations in temperatures throughout the day. Heat parameters were collected 3 times a day (0600, 1500 and 1800 hour). Respiration rates were obtained by counting flank movements for 15 sec and multiplied by 4 for a total of breaths per minute. Surface temperatures were measured on a shaved patch (~5 cm^2) of skin on the shoulder of the animal using an infrared temperature gun (Raynger®MX™, model RayMX4PU, Raytek C, Santa Cruz, CA). Using a standard digital thermometer (GLA M700 Digital Thermometer, San Luis Obispo, CA), rectal temperatures were measured. Environmental parameters were recorded hourly, and ambient temperature (T_{db}) and RH were used for calculations of THI.

Statistics

Data was analyzed using ANOVA and REGRESSION procedures of SAS (SAS, 1999). Milk yields were recorded during the acclimation periods and prior to environment initiation and were included as a covariate in the analysis. The dependent variables analyzed were milk yield, RR, ST, RT, HR, and EVHL. The independent variables included daily THI, ST, surface THI and BGHI. 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

Respiration rates and RT increased as THI values increased (Figures 1 and 2). Respiration rates increased by 2.0 breaths per minute per increase in THI unit (Figure 2). Evaporative heat loss was also found to increase as rectal temperatures were increased (Figure 3), indicating the animals was above its upper critical temperature.As rectal temperatures increased, milk yields were shown to decrease linearly (Figure 4). As THI increased, decreases in milk yield were observed (Figure 5). Milk yield decreased as ST temperature increased (not shown). When the average daily THI was equal to 68 over a 24-hour period, milk yield was reduced by -0.2831 kg (-0.62 lb) per hour ($P < 0.001$; $r^2 = 0.14$). When the average daily THI was equal to 71 over a 24-hour period, production declined -0.3033 kg (-0.67 lb) per hour ($P < 0.001$; $r^2 = 0.15$). When the average daily THI was equal to 72 over a 24-hour period, milk yields were reduced by -0.3217 kg (-0.71 lb) per hour ($P < 0.001$; $r^2 = 0.16$). Milk yields were shown to decrease linearly as THI values, RT, and EVHL increased (Figures 4 and 5). The decreases seen linearly in milk yield between the THI values of 60 and 80 indicate that the effects of heat stress are being observed before the threshold used currently of 72. Minimum THI on any given day when greater than 65 resulted in the beginning of milk yield losses (Table 1). When THI values were between 65 and 73, the average milk yield loss was 4.84 lb/day; this was also observed when THI was at an average THI of 68 for greater than 17 hours.

Adding solar radiation for a more accurate or ideal method of evaluating heat stress in determining the BGHI was of interest. During these studies, BGHI was only able to be calculated from 4 of the 8 groups due to the solar radiation treatments or technical difficulties; therefore, a small number of observations are attributed to the lower values, and any correlation observed was too small. No evidence was produced that BGHI would be a superior indicator of heat stress than THI on milk yield losses.

Nutritional Strategies

One of the primary strategies to maximize performance of cattle during warm summer months are to alter the nutritional management to maximize feed intake and substrate utilization. During periods of heat stress, the nutrient requirements of animals are altered, resulting in the need to reformulate rations. For example, if DMI decreases, then an increase in nutrient density is required, along with recalculating mineral and water requirements due to increased potassium loss in sweat (Collier et al., 2005). Reductions in DMI are major contributors to decreased milk production (Collier and Beede, 1985; Collier et al., 2005). When cows are heat-stressed, there is also a reduction in rumination and nutrient absorption and an increase in maintenance requirements, which results in a net decrease in nutrient/energy availability for production (Collier and Beede, 1985; Collier et al., 2005).

Studies by Rhoads et al. (2009) have shown the reduction in DMI may only be responsible for 36% of the decrease in milk production when cows are heat-stressed and 64% can be explained by other changes induced by heat stress. This raises the possibility that some of the loss in milk yield during thermal stress might be recoverable through appropriate nutritional management. In fact, Rhoads et al. (2009) demonstrated evidence of re-prioritization of post absorptive nutrient partitioning in heat stressed animals as the mobilization of adipose tissue is non-existent, contrary to the findings of increased cortisol, norepinephrine, and epinephrine during acute heat stress (Collier et al., 2005) that would normally stimulate lipolysis and mobilization of adipose tissues, thus increased non-esterified fatty acids. Rather, glucose sparing mechanisms seem to be prevented during heat stress due to metabolic adaptations (Rhoads et al., 2009). This type of evidence has also been reported in other ruminant models (Sano et al., 1993; Itoh et al., 1998; and Ronchi et al., 1999). These findings have led to the concept that during heat stress, regardless of reduced DM intake, cows are not able to mobilize adipose tissue, for example, in a normal (transition) negative energy balance situation; therefore, there must be an alteration in post-absorptive energetic metabolism (Bernabucci et al., 2010). Since insulin is a potent antilipolytic hormone, increased basal insulin concentrations and stimulated insulin response during heat stress may explain the lack of an increase we would expect to observe in basal non-esterfied fatty acid concentrations in heat stressed cows (Vernon, 1992; Bernabucci et al., 2010). In heat stressed cows and heifers, it has been shown that there is an increase in concentrations of plasma urea nitrogen compared to cows experiencing a thermal neutral environment. Thus, skeletal muscle appears to be mobilized during heat stress (Ronchi et al., 1999; Baumgard and Rhoads, 2007; Shwartz et al., 2009).

Other nutritional approaches to decrease the effect of heat stress are to reduce fiber intake to levels where the rumen can function properly, adding fat (high energy content and low heat increment), implementing higher concentrate diets with caution, and more recently niacin supplementation (Morrison, 1983; Collier and Beede, 1985; Knapp and Grummer, 1991). Niacin (nicotinic acid) is a potentially useful supplement because it induces vasodilation, therefore transferring body heat to the periphery (Di Costanza et al., 1997). Transferring body heat to the surface through peripheral or vasomotor function can perhaps alleviate some of the decrease in DMI and thus maintain milk production. Researchers have reported niacin to decrease skin temperatures during periods of mild to severe heat stress when supplemented at 12, 24, or 36 g of raw niacin for 3 consecutive 17-day periods (Di Costanza et al., 1997). When supplementing raw niacin, the amount of niacin degraded or absorbed in the rumen is much larger than the amount that reaches the small intestine (~17 to 30%; NRC, 2001). Past research observing the effects of niacin on heat stress has only looked at raw niacin; however, encapsulated niacin was recently evaluated at the University of Arizona.

University of Arizona Study - Encapsulated Niacin

Materials and Methods

Twelve multiparous Holstein cows producing an average of 56 lb/day and balanced for parity and stage of lactation were randomly assigned to either 0 g niacin (control) or 12 g /day of encapsulated niacin (Niashure™, Balchem Encapsulates, New Hampton, NY) and were exposed to 2 environmental temperature patterns. Temperature patterns were thermoneutral **(TN)** and HS. The THI range of TN pattern never exceeded 72, while HS consisted of a circadian temperature range where THI exceeded 72 for 12 hours daily. Milk yield was measured twice daily and sampled once a day for composition analysis. Water intake was recorded daily. Cows were fed twice daily, and feed refusal was measured daily. Respiration rates, ST of both shaved and unshaved areas taken at the rump, shoulder, and tailhead, and sweating rates of the shoulder at shaved and unshaved areas were taken 4 times daily. Rectal temperatures were measured 4 times daily.

Results

Dry matter intake was not affected by diet but decreased ($P < 0.05$) during HS (85.6 vs. 82.9 lb/day; Table 2). Milk yield did not differ between dietary groups or environments (Table 2). Surface temperatures obtained from the shoulder, rump and tail head were unaffected by niacin feeding but were affected by removal of the hair coat. When the hair coat was removed, the mean skin temperature was higher (90.5 vs. 88.5°F for shaved and unshaved, respectively; P < 0.05, data not shown). However, the difference between skin and hair coat temperature did not differ by environment (TN vs HS). All ST in both dietary groups were higher in HS compared to TN (Table 3). Evaporative heat loss was measured on shaved and unshaved skin to determine the impact of hair coat on EVHL. The EVHL for the 4 daily measurements was lower in both groups during TN and increased during HS (Table 3). In addition to the effect of environment (TN vs. HS), there was an effect of time of day on EVHL measurements, as values were low in the morning and rose as environmental temperatures in the room increased in the afternoon hours (P < 0.01, Figure 6). The NI fed cows had higher mean EVHL for both shaved and unshaved areas across the 4 time points measured during the HS period but not during TN (Table 3, Figure 6). Furthermore, these differences became larger in measurements taken during peak thermal stress. The EVHL for NI fed cows was higher ($P < 0.0001$) than for C fed cows in HS between 1000 and 1600 hours, (Figure 6), resulting in a diet by period interaction (Table 3). During the TN period, RT did not differ between diets, but the NI fed cows had decreased average RT during HS (100.7 vs. 101.0°F; Table 3) compared to control animals and lower mean core (vaginal) temperatures (100.4 vs. 101.1°F; $P < 0.001$; Figure 7). The pattern of rectal and vaginal temperatures demonstrated clear increases in both measures of core body temperature during afternoon hours. In HS during the hottest part of the day (1400 to 1700 hour), cows supplemented with NI had reduced heat storage compared to C (30.54 vs. 30.71 kcal/kg of BW; $P < 0.05$, data not shown). We concluded that cows given encapsulated niacin had higher sweating rates and lower core temperatures during acute thermal stress.

Conclusions

Environmental modifications to alleviate heat stress have resulted in dramatic gains in production in the southwestern United States; however, further research and evaluation is needed to provide producers with more efficient and economical solutions. While the new THI indicates the initial decreases in milk production at 68, further research is needed in order to effectively manage cooling methods and when they should be implemented. Further research on encapsulated niacin supplementation to evaluate the effects on commercial dairy farms to evaluate any production benefits should be conducted; however, the benefits of supplementing with encapsulated niacin have shown to be an increase in evaporative heat loss (sweating rate). Mechanisms behind heat stressed animals not mobilizing adipose tissue but rather skeletal muscle and the increased insulin sensitivity should be further investigated.

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Table 1. Effect of minimum temperature humidity index (THI) on milk yield in lactating Holstein cows producing greater than 70 lb/day of milk.

Minimum THI	Slope (lb/day)	P-value
49	-2.22	0.26
50	1.21	0.72
51	0.46	0.52
55	-0.62	0.76
63	-0.20	0.86
64	-0.09	0.91
65	-5.79	<0.01
66	-4.49	<0.01
70	-7.04	<0.01
73	-2.38	0.02

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

	Treatment							
	Thermoneutral		Heat Stress		Probabilty			
Variable	C[1]	NI[2]	C	NI	Diet	Period	Diet*Period	SEM[3]
Dry matter intake, lb/day	46.5	46.1	46.2	43.7	0.69	0.05	0.14	2.06
Water intake, L/day	40.4	52.7	48.6	57.7	0.11	<0.01	0.45	0.77
Milk yield, lb/day	64.6	67.2	64.8	65.3	0.17	0.35	0.25	0.84
Fat, %	3.94	4.00	3.77	3.51	0.55	0.06	0.36	0.17
Milk fat, lb/day	2.54	2.45	2.45	2.29	0.97	0.04	0.89	0.20
Protein, %	2.86	2.76	2.99	2.91	<0.01	<0.01	0.77	0.02
Milk Protein, lb/day	1.83	1.85	1.94	1.89	0.71	0.30	0.19	0.07
Lactose, %	4.68	4.66	4.69	4.69	0.66	0.062	0.75	0.03
Lactose, lb/day	3.02	3.13	3.04	3.06	0.10	0.37	0.19	0.13
Solids-not-fat, %	8.55	8.44	8.67	8.59	<0.01	<0.01	0.71	0.02
Solids-not-fat yield, lb/day	5.53	5.66	5.60	5.60	0.82	0.97	0.89	0.13

[1]Control (0 g Niashure™).
[2]NI = Treatment (12 g/day Niashure™).
[3]SEM = Standard error of mean.

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

	Period 1 Thermoneutral		Period 2 Heat Stress		Probability			
Variable[5]	C[1]	NI[2]	C	NI	Diet	Period	Diet*Period	SEM[3]
Surface Temperature, °F								
Shoulder, shaved	88.3	87.6	93.7	93.4	0.62	<0.01	0.88	32.4
Shoulder, non-shaved	85.8	85.3	92.1	92.5	0.32	<0.001	0.23	32.4
Rump shaved	88.5	88.3	94.1	94.1	0.85	0.05	0.74	32.3
Rump, non-shaved	86.7	86.5	92.8	92.7	0.92	<0.01	0.97	32.4
Tail head, shaved	86.9	87.2	92.1	92.7	0.18	<0.05	0.89	32.4
Tail head, non-shaved	83.1	83.3	91.0	90.7	0.93	<0.001	0.65	32.5
EVHL[4]								
Shaved, g/m^2/hour	23.2	18.3	92.4	114.4	0.36	<0.001	0.001	4.90
Non-shaved[4], g/m^2/hour	18.2	13.1	87.2	101.7	0.36	<0.001	0.001	4.89
Respiration rate, bpm	30.6	32.5	50.8	54.5	0.14	<0.001	0.59	2.01
Rectal temperatures, °F	100.4	100.5	101.0	100.7	0.05	<0.001	0.07	32.1

[1]C = Control (0 g Niashure™).
[2]NI = Treatment (12 g/day Niashure™).
[3]SEM = Standard error of mean.
[4]Closed chamber evapometer.
[5]Variables represent mean for all 4 measurement times.

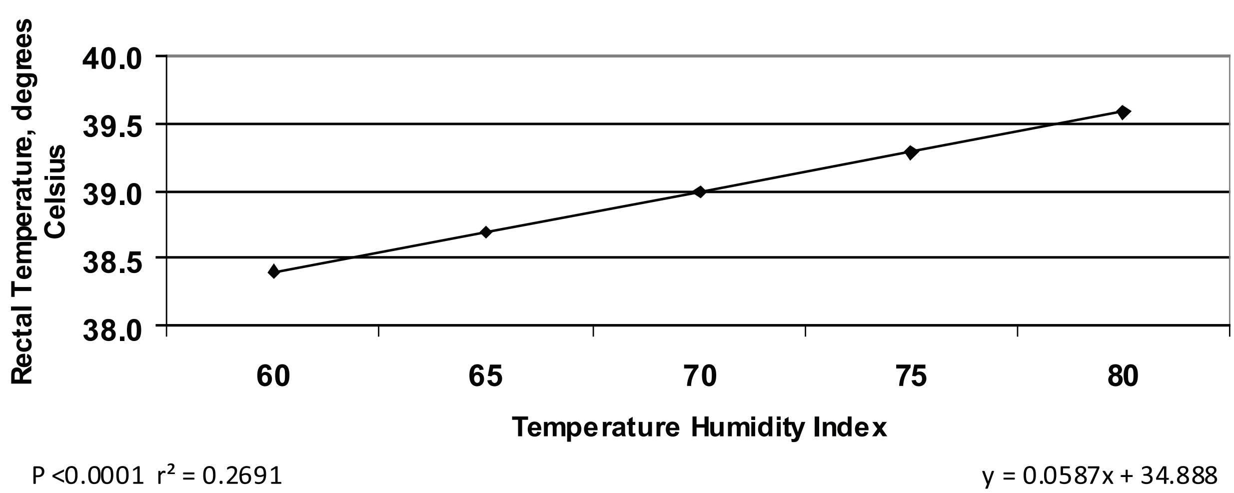

Figure 1. Temperature Humidity Index versus rectal temperatures.

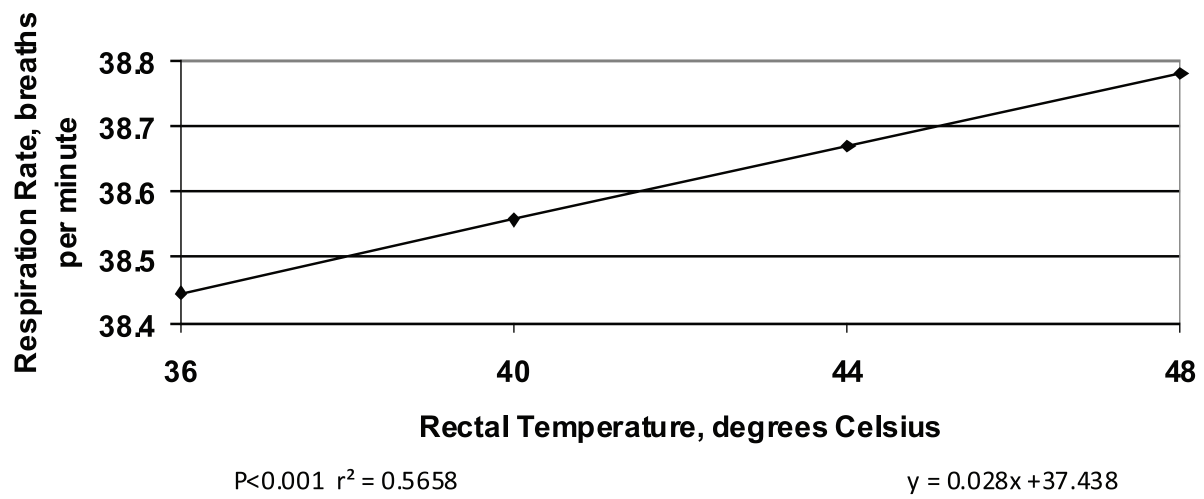

Figure 2. Rectal temperature versus respiration rate.

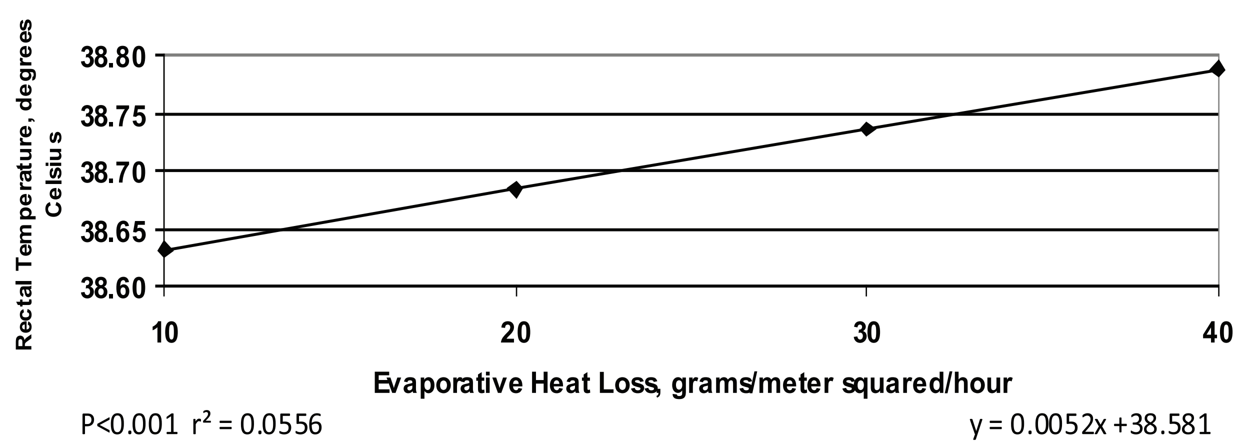

Figure 3. Rectal temperature versus evaporative heat loss.

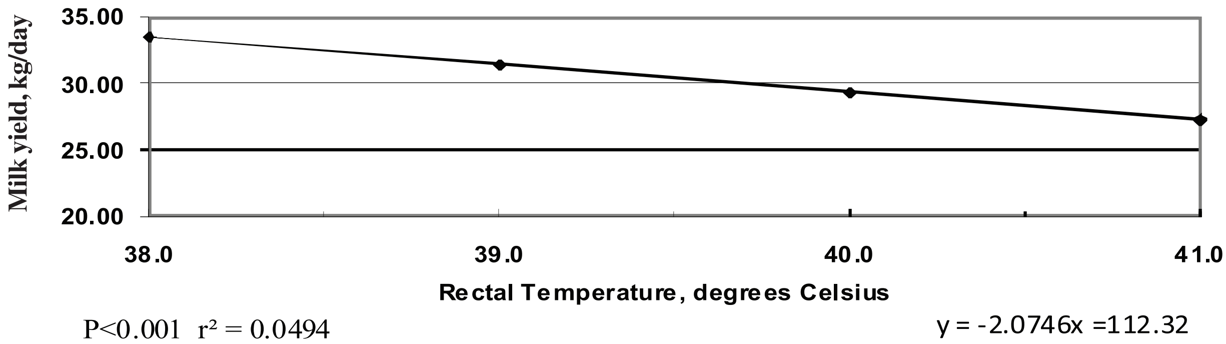

Figure 4. Rectal temperature versus milk yield.

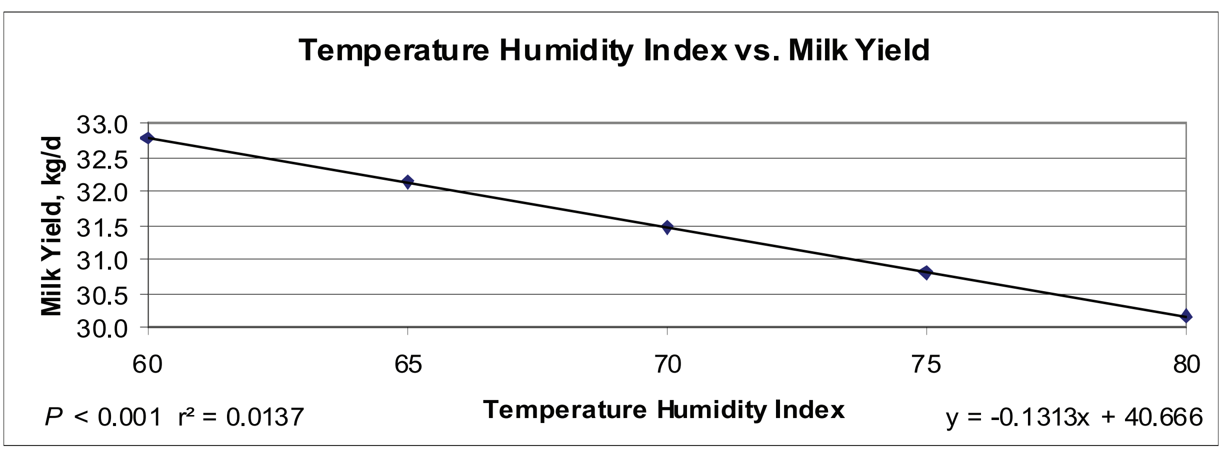

Figure 5. Temperature Humidity Index versus milk yield.

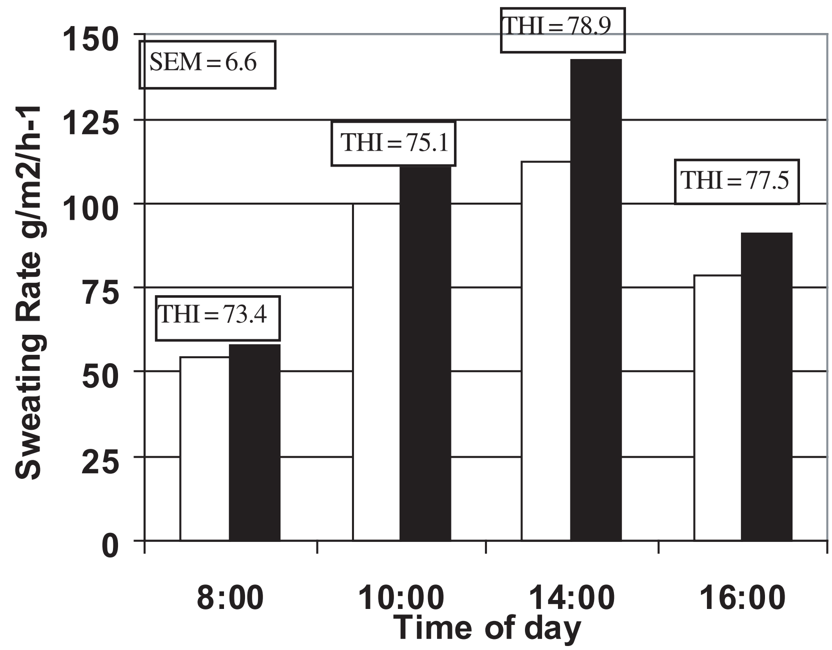

Figure 6. Effect of Temperature Humidity Index (THI) on mean evaporative heat loss in Control (clear) and Niashure (black) fed cattle at 0800, 1000, 1400 and 1600 hour during heat stress. The THI values in the boxes represent THI at the times measurements were was taken. (SEM = standard error of mean).

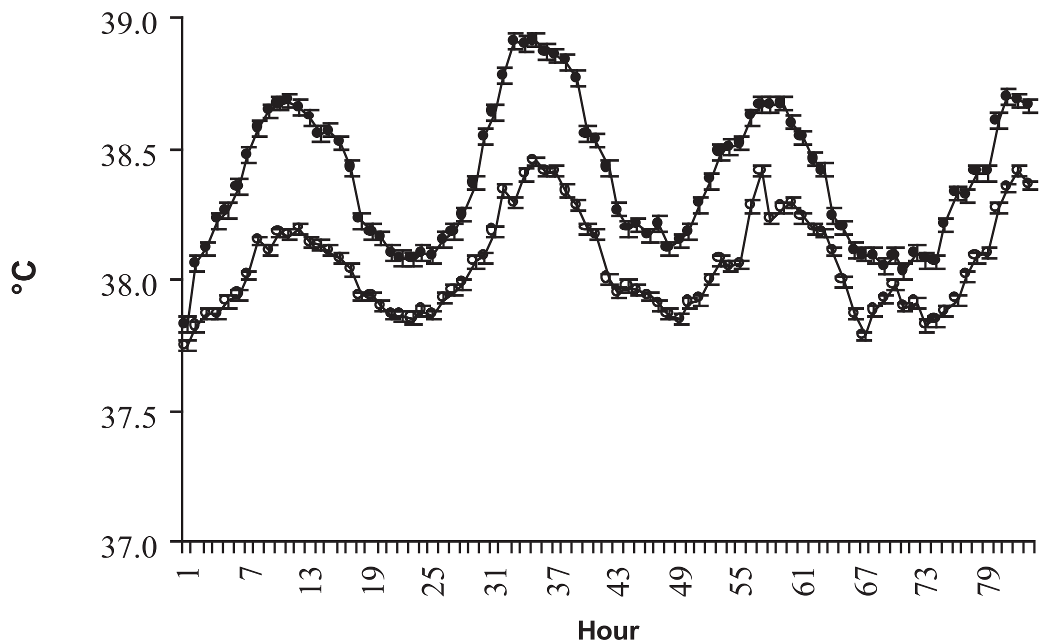

Figure 7. Core (vaginal) body temperatures of lactating Holstein cows supplemented with 0 g (●) or 12 g/ day of encapsulated niacin (❍) during day 4 to 7 of period 2.