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Short communication: Relationships among temperature-humidity index with rectal, udder surface, and vaginal temperatures in lactating dairy cows experiencing heat stress

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ABSTRACT

The objective of this study was to evaluate relationships between measurements of temperature-humidity index (THI) and rectal, vaginal, and udder surface temperatures in lactating cows exposed to heat stress (HS). In experiment 1, 12 multiparous and 8 primiparous Holstein cows experienced a THI ranging from 69 to 76 at 2000 to 1000 h and THI from 74 to 82 at 1000 to 2000 h (peaked at 82 from 1400 to 1800 h). Cows were exposed to HS 10 h daily for 21 d. Measurements of rectal temperature (RT) and udder surface temperature were collected at 1000 and 1500 h (±30 min). Vaginal temperature was monitored every 10 min using digital loggers, averaged over 1 h, and paired with corresponding rectal and udder surface temperature data. In experiment 2, 12 multiparous Holstein cows experienced a THI ranging from 60 to 76 at 2000 to 1000 h and THI from 69 to 83 at 1000 to 2000 h (peaked at 83 from 1600 and 1900 h), eliciting 10 h/d of HS for 7 d. Rectal and udder surface temperatures were analyzed at 0700 and 1500 h (±30 min). Vaginal temperature was recorded and analyzed as indicated in experiment 1. Afternoon THI showed weak correlations with surface temperature (r = 0.19, n = 420 in experiment 1; r = 0.23, n = 84 in experiment 2), weak to moderate correlations with RT (r = 0.34, n = 366 in experiment 1; r = 0.26, n = 84 in experiment 2), and moderate correlations with vaginal temperature (r = 0.34, n = 175 in experiment 1; r = 0.35, n = 40 in experiment 2). Moreover, vaginal temperature increased 0.10 and 0.22°C per unit of THI (R^2 = 0.15 in experiment 1; R^2 = 0.40 in experiment 2). Afternoon vaginal temperature strongly correlated with RT (r = 0.69, n = 131 in experiment 1; r = 0.63, n = 37 in experiment 2) and explained 57 (experiment 1) and 68% (experiment 2) of variation in RT. Surface temperature showed moderate to strong correlations with RT (r = 0.57, n = 84) and vaginal temperature (r = 0.74, n = 37) in experiment 2. In conclusion, THI showed a weak to moderate relationship with core body temperatures and explained the increase in rectal and vaginal temperatures experienced by HS cows. Compared with rectal temperature, vaginal temperature showed stronger relationships with THI and can be used to determine thermal load. Udder surface temperature showed a moderate to strong relationship with core body temperature, and this relationship may support the use of surface temperature data to manage thermal load in HS cows.
Key words: body temperature, dairy cow, heat stress

Short Communication

The temperature-humidity index (**THI**) is estimated using ambient temperature and relative humidity and is used to determine heat stress (**HS**) conditions for lactating dairy cows. A decline in the thermal gradient between an animal and its environment due to HS compromises the loss of metabolic heat and contributes to heat load. The THI correlates with rectal temperature (**RT**) and explains the increase in body temperature of HS cows in subtropical environments (Dikmen and Hansen, 2009). Measurement of RT is used to determine core body temperature in dairy cattle; however, this procedure disrupts animal behavior and can be time-consuming and labor intensive (Burdick et al., 2012). Alternatively, monitoring udder surface temperature by thermal imaging is a quick, noninvasive procedure (Berry et al., 2003; Montanholi et al., 2008). However, udder surface temperature and the daily pattern of udder surface temperature differ with that of RT (Montanholi et al., 2008). A weak relationship between RT and udder surface temperature might limit the use of thermal imaging to monitor changes of body temperature in HS dairy cattle (Cvetkovic et al., 2005). Recent work indicates that infrared thermography detected changes in temperature on the right and left flanks and showed strong correlation with heat production (r = 0.62 and 0.72; Montanholi et al., 2008). Thus, monitor-

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ing udder surface temperature is less laborious than the determination of RT and could be an effective method to determine HS in cattle.

Compared with RT, the use of digital thermometers to monitor vaginal temperature can reduce the disruption of animal behavior (Collier et al., 2006; Montanholi et al., 2008) and provide continuous measurements of core body temperature (Collier et al., 2006). Vickers et al. (2010) demonstrated that rectal and vaginal temperatures were strongly correlated ($r = 0.81$) immediately postcalving and moderately correlated ($r = 0.46$) at peak lactation. In another study, rectal and vaginal temperatures were strongly correlated ($r = 0.89$) 48 h before calving (Burfeind et al., 2011). Although various physiological states alter surface and core body temperatures, the relationship of these parameters with THI have not been measured on lactating dairy cows experiencing thermal stress. The first objective of our study was to assess the relationship among THI and body temperatures in lactating dairy cows exposed to HS. The second objective was to evaluate the relationship between rectal, vaginal, and udder surface temperature. We hypothesized that THI would correlate and explain changes in rectal, vaginal, and udder surface temperatures in cows exposed to HS; likewise, vaginal and udder surface temperatures would display a strong relationship and explain changes in RT of cows exposed to HS.

All experimental methods were reviewed and accepted by the University of Tennessee, Institutional Animal Care and Use Committee. In experiment 1, Holstein lactating cows (144 ± 49 DIM; 12 multiparous and 8 primiparous) were housed in a sand-bedded freestall barn at the East Tennessee Research and Education Center-Little River Animal and Environmental Unit (Walland, TN). Cows were fed a TMR at 0900 h with a 50:50 forage-to-concentrate ratio on a DM basis containing varying amounts of CP and similar NE_L content (Kaufman et al., 2017). Cows were milked at 0900 and 1900 h and cooled during milking. Cows experienced prevailing east Tennessee climate for the months of July and August, and evaporative cooling was not provided to mimic diurnal changes of climate for 21 d. Measurement of ambient temperature (T) and relative humidity (RH) were used to determine THI using the following equation (Dikmen and Hansen, 2009):

$$\text{THI} = (1.8 \times \text{T} + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times \text{T} - 26)].$$

Temperature-humidity index ranged from 69 to 76 at 2000 to 2400 and 0100 to 1000 h and 74 to 82 at 1000 to 2000 h (peaked at 82 from 1400 to 1800 h). Temperature-humidity index >68 was indicative of HS (Cook et al., 2007) and we imposed HS for an average of 10 h daily.

Rectal temperature (n = 8 multiparous and 8 primiparous cows) was measured at 1000 and 1500 h (±30 min) throughout the study using a GLA M700 battery-operated digital read out thermometer (GLA Agricultural Electronics, San Luis Obispo, CA; accuracy ±0.1°C). Vaginal temperature was monitored using an intravaginal data loggers (DS1922L Thermochron iButton Device; Maxim Integrated, San Jose, CA; size = 17.4 × 5.9 mm; weight = 3.3 g; accuracy ±0.5°C) inserted into modified, blank (progesterone-free) internal drug release device (Zoetis, Florham Park, NJ) that was adapted as indicated previously (Dikmen et al., 2008; Burdick et al., 2012). The accuracy of intravaginal temperature loggers was tested using a 37.0°C water bath at 10-min intervals for 24 h as previously described (Burdick et al., 2012). Intravaginal loggers recorded temperature values every 10 min on d 11 to 15 (n = 5 multiparous and 2 primiparous cows) and d 16 to 20 (n = 7 multiparous and 6 primiparous cows). Vaginal temperature data were averaged by periods of 1 h (±30 min) and paired with corresponding RT (i.e., 1000 and 1500 h on d 11 to 15 and d 16 to 20; Vickers et al., 2010). Udder surface temperature was measured at 1000 and 1500 h (±30 min) using an infrared imaging gun (FLIR TG165 Imaging IR Thermometer; Wilsonville, OR; accuracy ±1.5°C) on a clean area of the left rear quarter. Measurements were consistently taken on animals standing for longer than 5 min and at a distance of 15 cm from the udder. Air velocity was not measured, however, it may have influenced the relationship between udder surface and core body temperature. Udder composite milk samples were collected to determine SCC and evaluate inflammatory status of the mammary glands. Milk SCC did not change throughout the study (reported elsewhere; Kaufman et al., 2017).

In experiment 2, multiparous Holstein cows (n = 12; 120 ± 12 DIM) were housed in tiestalls in a temperature-controlled chamber at the East Tennessee Research and Education Center-Johnson Animal Research and Teaching Unit (Knoxville, TN). Cows were housed for a 3 d adaptation to facilities, followed by 7 d of HS. All cows were individually fed at 0600 and 1700 h a common TMR at 10% daily refusal (45% forage and 55% concentrate on DM basis) and milked at 0700 and 1800 h with no supplemental cooling. The HS treatment was designed to mimic a cyclical pattern of hot summer days in the southeastern United States. Temperature-humidity index was determined throughout the experiment and HS was determined as indicated in experiment 1. Temperature-humidity index