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Are My Dry Cows Heat-Stressed? A Novel Approach to Assess Heat Stress of Dry Cows in Commercial Dairy Herds

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Abstract

Heat stress during the dry period causes major economic losses to the dairy industry. However, limited research exists regarding responses of dry cows exposed to various temperature and relative humidity gradients. In addition, no validated methods are currently available to assess heat stress in dry cows. The goals of this study were to describe core body temperature (CBT) responses of dry cows according to a variety of temperature-humidity index (THI) values, and develop and validate a practical method to assess heat stress in dry cows in commercial dairy herds. This study was comprised of 2 parts. In the first part of the study, vaginal temperature of dry cows (n = 346) with 250 to 260 days of gestation from 5 herds was assessed for 4 to 7 consecutive days in 5-minute intervals. Within dairy and parity group, cows were classified as having high (HT) or low CBT (LT). By design, CBT was greater for HT compared with LT cows (102.3 ± 0.01 vs. 101.8 ± 0.01°F). Cows classified as having HT had shorter gestation length compared with their LT counterparts (272.5 ± 0.2 vs. 275.1 ± 0.2 days). The second part of the study consisted of evaluating and validating a practical assessment method of heat stress and investigating CBT threshold values. Vaginal temperature of 1,540 dry cows with 236 to 250 days of gestation from 3 commercial dairy herds was assessed a single time using a digital thermometer. Average CBT of HT cows at each THI (data from the first part of the study) was used as a threshold value to classify cows as heat-susceptible or heat-tolerant. Cows with higher or lower CBT than the threshold defined for a given THI were classified as heat-susceptible or tolerant, respectively. Cows classified as heat-susceptible had shorter gestation length (272.5 ± 0.2 vs. 275.0 ± 0.2 days) and were more likely to have twins (11.0 vs. 3.8%) than heat-tolerant cows. In conclusion, assessment of heat stress in dry cows based on defined CBT thresholds is a useful method to identify cows expected to have shorter gestation length and more likely to have twins.

Keywords

summer, dry cows, assessments method, gestational length

Cover Page Footnote

The authors thank the owners and employees of the collaborating dairies.

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Summary
Heat stress during the dry period causes major economic losses to the dairy industry. However, limited research exists regarding responses of dry cows exposed to various temperature and relative humidity gradients. In addition, no validated methods are currently available to assess heat stress in dry cows. The goals of this study were to describe core body temperature (CBT) responses of dry cows according to a variety of temperature-humidity index (THI) values, and develop and validate a practical method to assess heat stress in dry cows in commercial dairy herds. This study was comprised of 2 parts. In the first part of the study, vaginal temperature of dry cows (n = 346) with 250 to 260 days of gestation from 5 herds was assessed for 4 to 7 consecutive days in 5-minute intervals. Within dairy and parity group, cows were classified as having high (HT) or low CBT (LT). By design, CBT was greater for HT compared with LT cows (102.3 ± 0.01 vs. 101.8 ± 0.01°F). Cows classified as having HT had shorter gestation length compared with their LT counterparts (272.5 ± 0.2 vs. 275.1 ± 0.2 days). The second part of the study consisted of evaluating and validating a practical assessment method of heat stress and investigating CBT threshold values. Vaginal temperature of 1,540 dry cows with 236 to 250 days of gestation from 3 commercial dairy herds was assessed a single time using a digital thermometer. Average CBT of HT cows at each THI (data from the first part of the study) was used as a threshold value to classify cows as heat-susceptible or heat-tolerant. Cows with higher or lower CBT than the threshold defined for a given THI were classified as heat-susceptible or tolerant, respectively. Cows classified as heat-susceptible had shorter gestation length (272.5 ± 0.2 vs. 275.0 ± 0.2 days) and were more likely to have twins (11.0 vs. 3.8%) than heat-tolerant cows. In conclusion, assessment of heat stress in dry cows based on defined CBT thresholds is a useful method to identify cows expected to have shorter gestation length and more likely to have twins.

Introduction
Heat stress causes major economic losses to the dairy industry. Several studies demonstrated that exposure of lactating dairy cows to heat stress increases core body temperature (CBT) and reduces productive and reproductive performance. Recent studies indicate that the negative effects of heat stress are not limited to the lactating period. Dairy cows exposed to heat stress during the dry period have impaired milk yield in

the subsequent lactation. Because of the extensive impact of heat stress on dairy cows, research has been conducted on this topic for several decades.

In order to estimate severity of heat stress conditions to dairy cows, during the 1960s researchers developed the temperature-humidity index (THI), which has been revised several times in the past decades to account for increased milk production of modern dairy cows. It is currently widely accepted that a THI $\geq$ 68 is associated with reduced performance of lactating cows. Despite the scientific evidence that a THI $\geq$ 68 is an appropriate threshold to indicate heat stress in lactating dairy cows, no studies have evaluated the THI threshold of heat stress for dry cows. In addition, the lack of data on CBT responses according to THI in dry cows is a significant limitation for determining whether conditions are predisposing a large proportion of cows to be susceptible to heat stress. Indeed, monitoring tools and screening tests to assess severity of heat stress in dry cows in commercial herds are not currently available.

Exposure to heat stress during the dry period reduces gestation length in dairy cows. Thus, gestation length is expected to be shorter in herds in which dry cows are severely affected by heat stress. Shorter gestation length has been associated with several post-partum problems, such as increased incidence of retained placenta and metritis, and reduced reproductive performance and milk yield. Therefore, there is a need to develop an effective method to assess severity of heat stress in dry cows to assist producers and consultants to determine whether heat abatement strategies should be implemented.

The primary objective of the present study was to describe CBT responses of dry cows from commercial herds according to a variety of THI values during summer. Our secondary objectives were to develop and validate a practical method to assess heat stress in dry cows in commercial dairy herds.

Experimental Procedures

The present study consists of a compilation of data from three previous experiments. Data analyses in the current study were conducted in two parts, which are referred to as "reference dataset" (part 1) and "validation" (part 2). These terms were used to define whether the data were used to develop the heat stress assessment method (e.g., reference dataset) or to evaluate its usefulness in commercial herds (e.g., validation).

Reference Dataset and Definition of CBT Threshold Values

Data used for this part of the study were from experiments conducted during the summer of 2014 (n = 2 herds) and 2017 (n = 3 herds) in Kansas dairy farms. Herds used in the study had on average 2,210 milking cows (range = 250 to 4,000). Dry cows were housed in free-stall barns (2 herds), dry-lot pens (2 herds), or a bedded pack barn (1 herd). Cows had access to shade in all herds and an evaporative cooling system was provided for cows housed in the free-stall and bedded pack barns (3 herds). Dry Holstein cows (n = 346) at 250 to 260 days of gestation and with no signs of clinical disorders were enrolled in the study in weekly cohorts. To ensure all cows were exposed to similar environmental conditions, enrollment was conducted when weather forecasts predicted maximum temperatures greater than 90°F for 7 consecutive days. Upon enrollment, a calibrated temperature logger (iButton DS1922L, Embedded Data Systems, Lawrenceburg, KY) attached to a blank CIDR was inserted into cows' vaginas.

Loggers were programmed to record CBT in 5-minute intervals for 4 to 7 consecutive days. After removal of loggers, average CBT was calculated for each cow. Median values of CBT were calculated within each dairy and parity group. Cows with average CBT greater or equal to the median value were classified as having high CBT (HT; n = 176), whereas cows with average CBT below the median value were considered to have low CBT (LT; n = 170). Cows were followed until the day of calving. Data regarding date of parturition, gestation length, and pregnancy type (e.g., singleton or twins) were extracted from the on-farm management software (3 herds: DairyComp, Valley Ag Software, Tulare, CA; 2 herds: PCDart, DRMS, Raleigh, NC).

Ambient temperature and humidity were recorded in 5-minute intervals using loggers (HOBO U23 Pro v2, Onset Computer Corp., Pocasset, MA) located in the pens. Ambient THI was calculated using the equation: $THI = T - (0.55 - 0.55\ RH/100) \times (T - 58)$, where T and RH are dry-bulb temperature (°F) and relative humidity, respectively. To characterize CBT of cows across different THI values, ambient THI was identified at each time point that CBT was recorded (total of 563,673 data points). To create a CBT threshold to identify cows more susceptible to heat stress, the average of CBT of HT cows was calculated for each time point of THI available in the dataset. Therefore, based on the average CBT of HT cows for each THI time point, threshold values of CBT were established for various THI. Established threshold values of CBT according to THI were used in the second part of the study (validation of heat stress threshold values).

Validation of Heat Stress Threshold Values

Data used to validate the CBT threshold values were from an experiment conducted with dry Holstein cows in commercial herds located in Kansas (n = 2 herds) and Oklahoma (n = 1 herd) during the summer of 2018. Herds used for this part of the study had on average 4,500 milking cows (range = 4,000 to 5,500). Cows were housed in open dry-lot pens with access to shade. Once weekly, a list of cows with 236 to 250 days of gestation was generated using the on-farm management software (DairyComp, Valley Ag Software, Tulare, CA). A subset of cows (n = 50 to 70 per herd) were randomly selected from the list to be included in the study weekly. On the day of enrollment, eligible cows were evaluated by a veterinarian, and those that presented any clinical disorders (e.g., lameness) were not included in the study. Core body temperature was assessed from cows that met the inclusion criteria (n = 540, 508, and 492 for herds A, B, and C, respectively) using a high-precision thermometer (Fisherbrand Traceable Platinum Ultra-Accurate Digital Thermometer, Thermo Fisher Scientific, Waltham, MA). The one-time CBT assessments were conducted between 1900 and 2000 h. After parturition, gestation length and pregnancy type data (singleton vs. twins) were extracted from the on-farm management software.

Temperature and humidity in the pens were recorded in 5-minute intervals using loggers (HOBO U23 Pro v2, Onset Computer Corp., Pocasset, MA) fixed under the shade structures. Ambient THI at time of CBT assessment was calculated with the same formula used for the reference dataset.

Using the pre-established CBT threshold values according to THI (part 1 of study – reference dataset), cows were classified as heat-susceptible or heat-tolerant for validation of the heat stress threshold at a given ambient THI. Therefore, cows that presented CBT greater or equal to the pre-established threshold for each specific THI were considered to be heat-susceptible.

Statistical Analyses

Continuous variables were analyzed by ANOVA using the PROC GLIMMIX procedure of SAS with normal distribution and identity link. For dichotomous outcomes, the PROC GLIMMIX procedure of SAS with binary distribution and logit link was used, and incidence of events was calculated using the PROC FREQ procedure. Significance was declared at $P \leq 0.05$, and tendencies at $0.05 < P \leq 0.10$.

Results and Discussion

Study Part 1 – Reference Dataset

Core body temperature of dry cows at various THI values are depicted in Figure 1. These data add to the current knowledge of heat stress in dry cows given the large number of cows used in the study and hundreds of CBT measurements obtained in consecutive days from each cow. Furthermore, because all data were recorded in commercial dairy herds, it is likely that results reported herein accurately represent populations of cows from other commercial herds. Therefore, it is acceptable to speculate that data depicted in Figure 1 are useful for dairy producers and consultants when implementing heat abatement strategies for dry cows, such as activating fans and sprinklers based on THI values.

In the reference dataset, average CBT was ($P < 0.01$) greater for HT compared with LT cows (Figure 2; 102.3 ± 0.01 vs. 101.8 ± 0.01 °F). Although this difference occurred because of the way cows were classified into HT and LT groups, CBT values were consistently greater for HT than LT cows, regardless of THI. This indicates that the methodology used to classify dry cows into 2 groups in part 1 of the study was appropriate to identify heat-susceptible cows. Because cows were classified based on CBT within herd and, therefore, were exposed to similar nutritional and management conditions, it is possible to speculate that HT cows either had greater metabolic heat production or impaired heat loss compared with LT cows. Differences in behavioral characteristics, such as lying time, may be another reason for discrepancies in CBT. Cows classified as HT had ($P < 0.01$) shorter gestation length compared with their LT counterparts (272.5 ± 0.2 vs. 275.1 ± 0.2 days).

Study Part 2 – Validation

The authors recognize that the strategy used to classify cows as HT or LT requires specialized equipment (e.g., temperature loggers) and is time-consuming, which likely prevents its adoption and routine use in commercial herds. Therefore, the authors focused on using the reference dataset to establish temperature threshold values that could be easily used by dairy producers and consultants to determine groups of cows with increased CBT and, therefore, more prone to have short gestation length. Average CBT, gestation length, and incidence of twining for cows susceptible and tolerant to heat stress are summarized in Table 1. Overall, heat-susceptible cows had ($P < 0.01$) shorter gestation length (272.5 ± 0.2 vs. 275.0 ± 0.2 days) and greater ($P < 0.01$) risk of twin pregnancy (11.0 vs. 3.8%) than cows classified as heat-tolerant. The interaction between dairy and CBT group was not (P > 0.40) associated with gestation length or risk of twinning. This lack of interaction indicates that the pre-established CBT threshold values were appropriate to identify heat-susceptible cows (e.g., present short gestation length), regardless of the dairy where the method was applied. This is an important finding because it suggests that the proposed method to assess heat stress in dry cows may be useful for commercial operations. In addition, this method may be used as a heat stress screening test for dry cows.

Figure 3 depicts proportion of cows identified as heat-susceptible weekly at each dairy. Gestation length was consistently shorter for heat-susceptible than heat-tolerant cows in the 3 dairies across all weeks of CBT assessments (Figure 3). These data further indicate the effectiveness of the method adopted to identify heat-susceptible cows. Interactions between dairy and CBT group, week of CBT assessment and CBT group, and the three-way interaction between dairy, week of assessment, and CBT group were not (P > 0.58) associated with gestation length.

In conclusion, the method proposed to assess heat stress in dry cows using pre-established CBT threshold values is useful to identify cows expected to have shorter gestation length. Furthermore, the method described herein was useful to identify dry cows more likely to deliver twins. Because CBT assessments were conducted more than 2 to 3 weeks before expected calving, this system allows implementation of specific management practices targeted to cows more prone to have short gestation length and twins before parturition starts. Further studies are necessary to evaluate strategies to manage heat-susceptible cows to prevent disorders associated with short gestation length or twinning, such as retained placenta and metritis.

Acknowledgments

The authors thank the owners and employees of the collaborating dairies.

	Relative humidity, %																	
TEMP, °F	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
51																	101.6	101.5
52																	101.5	
53																	101.5	
54																	101.6	
55																101.4	101.7	
56																101.6	101.7	
57																101.6		
58														101.7	101.9	101.9	101.8	101.8
59													101.7	101.8	101.7	101.7	102.1	101.8
60													101.6	101.7	101.7	101.7	101.9	101.4
61													101.7	101.9	101.6	101.8	101.9	101.5
62													101.9	101.8	101.7	101.8	101.8	101.5
63												102.0	101.7	101.9	102.0	101.9	101.7	101.9
64												102.1	101.9	101.9	101.9	101.8	101.7	101.8
65											102.2	102.0	101.9	101.9	101.9	101.8	101.8	101.7
66										102.1	102.0	102.0	102.0	101.6	102.0	101.5	101.9	101.6
67										102.2	101.9	101.7	101.5	102.0	101.9	101.5	101.8	101.9
68									102.2	101.9	101.6	101.8	101.9	102.0	101.7	101.7	101.9	102.1
69									102.3	101.6	102.0	101.7	102.0	101.9	101.7	101.9	101.9	101.7
70									101.9	101.8	101.9	102.0	102.0	102.0	101.8	102.0	102.0	101.8
71								101.6	101.8	101.9	102.2	102.2	102.0	101.9	101.9	101.9	102.1	101.9
72								102.0	101.9	101.9	102.2	102.0	102.0	101.9	102.0	101.9	102.0	101.9
73							101.8	102.0	101.9	102.0	101.9	102.0	102.0	102.0	102.1	102.1	102.1	102.0
74							101.8	102.0	102.0	102.0	101.8	102.1	101.9	102.1	101.8	102.2	102.1	102.1
75							102.1	102.2	101.9	101.9	102.0	101.9	101.9	102.1	102.3	102.1	102.1	102.3
76							102.2	102.0	102.0	102.0	101.9	101.9	102.1	102.1	102.1	102.1	102.1	101.8
77						101.5	102.2	102.1	102.1	102.1	102.1	101.9	102.2	102.1	102.2	102.0	102.2	101.6
78						102.0	102.1	102.2	102.0	102.1	101.9	102.1	102.2	102.2	102.1	102.4	102.2	102.1
79					102.0	102.1	102.2	102.1	102.1	102.2	102.0	102.2	102.2	102.1	102.4	102.3	102.2	
80					102.0	102.1	102.2	102.1	102.3	101.9	102.2	102.3	102.2	102.3	102.4	102.0	101.9	
81				101.9	102.2	102.3	102.2	102.3	102.2	102.0	102.3	102.3	102.1	102.4	102.3	101.9	102.3	
82				101.8	102.2	102.3	102.3	102.3	102.2	102.2	102.3	102.3	102.2	102.5	102.2	102.3	101.8	
83				101.7	102.2	102.3	102.3	102.4	102.2	102.3	102.3	102.3	102.4	102.2	102.1	102.3	101.9	
84				101.9	102.0	102.3	102.3	102.3	102.3	102.3		102.2	102.4	101.9	102.3	101.7		
85			101.9	101.9	102.3	102.4	102.3	102.1	102.3	102.3	102.5	102.5	102.3	101.5	101.7	101.7		
86			102.0	102.1	102.4	102.4	102.2	102.1	102.3	102.3	102.3	102.1	102.1	102.0				
87			102.1	102.2	102.6	102.3	102.3	102.4	102.3	102.4	102.2	102.3	102.1	102.1				
88			102.2	102.5	102.5	102.3	102.4	102.3	102.3	102.5	102.1	102.3	102.1					
89			102.2	102.6	102.4	102.2	102.3	102.4	102.4	102.4	102.4	102.3	102.1					
90			102.3	102.5	102.3	102.4	102.3	102.4	102.4	102.4	102.2	102.3	102.3					
91				102.5	102.3	102.2	102.5	102.4	102.4	102.3	102.0							
92				102.2	102.3	102.4	102.5	102.5	102.6	102.4	102.3							
93			102.4	102.3	102.4	102.5	102.5	102.6	102.3	102.4								
94			102.4	102.4	102.5	102.5	102.5	102.5	102.3									
95			102.3	102.5	102.4	102.6	102.4	102.3	102.2									
96		102.2	102.4	102.3	102.5	102.5	102.5	102.7	102.0									
97	102.0	102.5	102.6	102.5	102.6	102.5	102.3	103.0	103.1	103.0								
98	102.0	102.3	102.4	102.5	102.6	102.5	102.2		102.9									
99	102.2	102.7	102.4	102.5	102.6	102.4												
100	102.4		102.5	102.6	102.5	102.3	102.2	102.3	102.6									
101	102.6		102.4	102.7	102.6	102.1	102.1	102.5										
102	102.6		102.4	102.7	102.5													
103			102.7	102.6														
104			102.9	102.5														
105			102.7															

Figure 1. Mean core body temperature responses of dry dairy cows (n = 346) to various combinations of ambient temperature (TEMP) and relative humidity. Core body temperature assessments were conducted every 5 minutes in dry cows between 250 and 260 days of gestation during the summer of 2014 and 2017 (study part 1 – reference dataset). Colors represent ranges of temperature-humidity index (THI), which was calculated for every time point of core body temperature. White, light gray, medium gray, and dark gray represent indexes of < 68, 68 to 72, 72 to 80, and > 80, respectively.

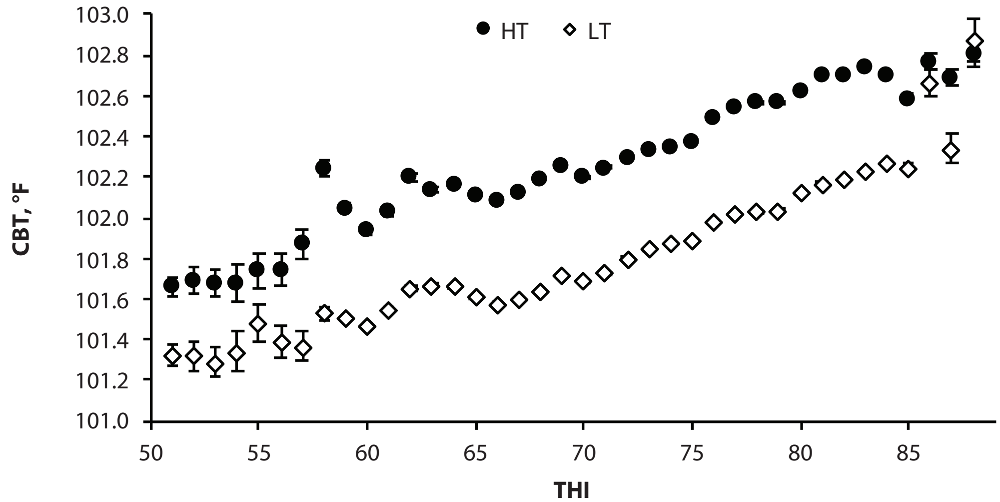

Figure 2. Average core body temperature (CBT) at various values of temperature-humidity index (THI) for dry dairy cows (n = 346) classified as having CBT higher (HT; black circles) or lower (LT; white diamonds) than the median value for their respective parity group and dairy. Assessments were conducted in cows between 250 and 260 days of gestation during the summer 2014 and 2017 (study part 1– reference dataset). Error bars represent standard error of the mean. Average CBT was greater (*P* < 0.01) for HT than LT cows (102.3 ± 0.01 vs. 101.8 ± 0.01 °F).

Table 1. Average (SEM[1]) core body temperature (CBT) in the dry period,[2] gestation length, and twinning incidence for dairy cows from three commercial dairy herds deemed as heat-susceptible and heat-tolerant based on pre-established threshold values[3,4] for validation of a method to assess heat stress of dry cows in commercial dairy herds

	CBT category[5]		
Item	Heat-susceptible	Heat-tolerant	*P*-value
Dairy A			
Number of cows	268	272	
Average core body temperature, °F	102.8 (0.03)	102.0 (0.03)	< 0.01
Gestation length, d	272.9 (0.3)	275.2 (0.3)	< 0.01
Twinning, %	11.2	4.8	0.01
Dairy B			
Number of cows	323	185	
Average core body temperature, °F	103.2 (0.02)	102.2 (0.03)	< 0.01
Gestation length, d	271.7 (0.3)	274.4 (0.4)	< 0.01
Twinning, %	9.6	1.6	< 0.01
Dairy C			
Number of cows	267	225	
Average core body temperature, °F	103.1 (0.03)	102.2 (0.03)	< 0.01
Gestation length, d	272.8 (0.3)	275.3 (0.4)	< 0.01
Twinning, %	12.4	4.4	< 0.01

[1]Standard error of the mean.
[2]Core body temperature was assessed in 1,540 cows during the summer of 2018 (study part 2 – validation of heat stress threshold values).
[3]Threshold values for classifying cows as heat-susceptible were the average CBT of cows with CBT above or equal the median value for their respective herd and parity group in the reference dataset.
[4]Reference dataset was comprised of records from 346 parous cows from 5 dairy herds that had CBT assessed between 250 and 260 days of gestation.
[5]Cows were classified as heat-susceptible or heat-tolerant based on pre-established CBT threshold values for the specific THI at CBT assessment (study part 1 – reference dataset).

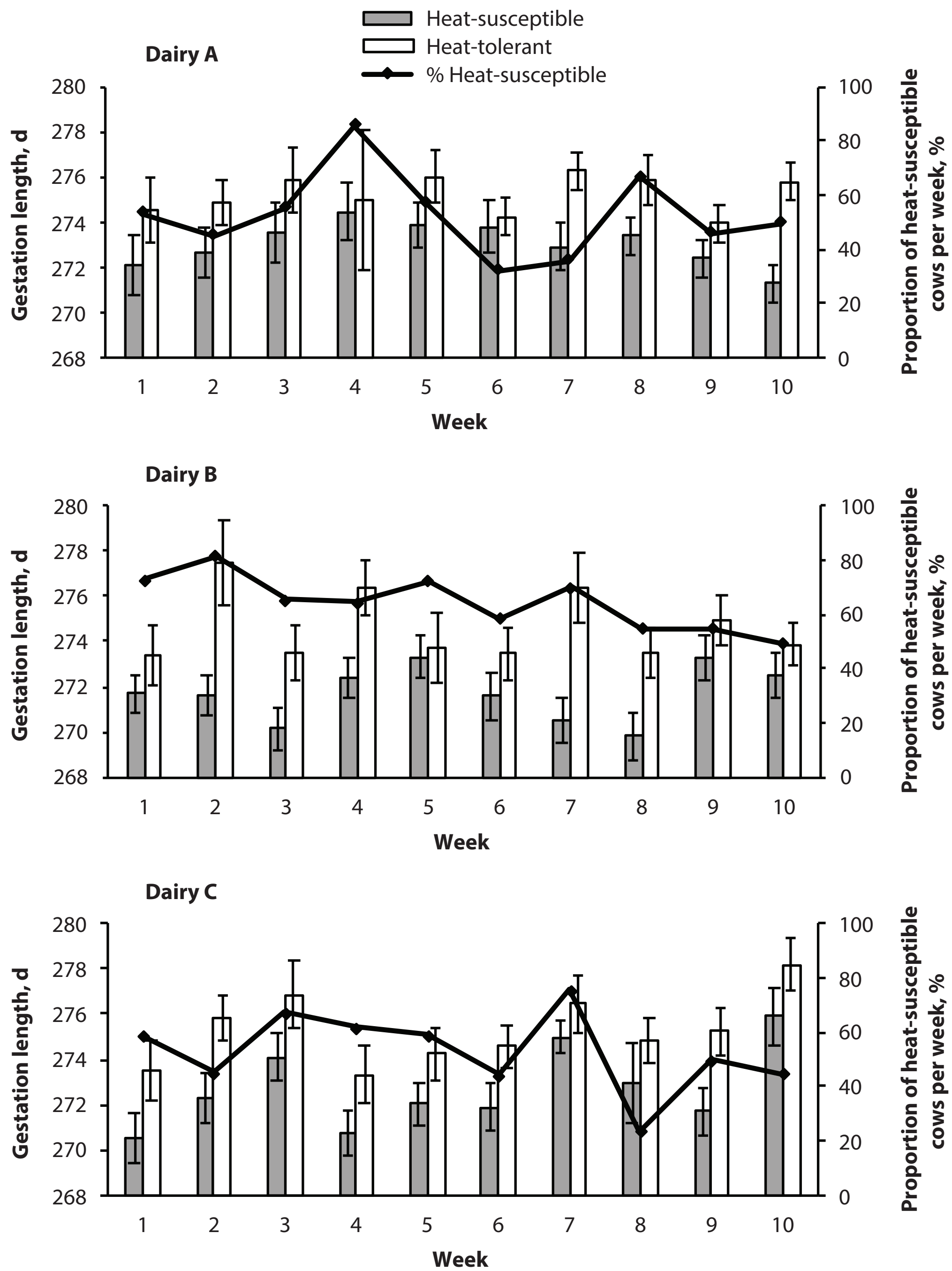

Figure 3. Left axis represents gestation length of cows from 3 commercial dairy herds identified as heat-susceptible or heat-tolerant weekly during the dry period based on core body temperature (CBT) threshold values previously defined from a reference dataset. Right axis represents the proportion of cows deemed heat-susceptible by week of temperature assessment. Error bars represent standard error of the mean.