Effects of weather variables on thermoregulation of calves during periods of extreme heat

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Objective—To determine effects of ambient temperature, relative humidity, wind speed, relative barometric pressure, and temperature-humidity index (THI) on nasal submucosal and rectal temperatures in cattle during extreme summer conditions.

Animals—20 black crossbred beef heifers (mean body weight, 217.8 kg).

Procedures—Nasal submucosal and rectal temperatures were monitored every 2 hours for 24 hours on 3 nonconsecutive days when ambient temperature was forecasted to exceed 32.2°C. Ambient temperature, relative humidity, wind speed, and relative barometric pressure were continuously monitored at a remote weather station located at the research facility. The THI was calculated and used in the livestock weather safety index (LWSI). Relationships between nasal submucosal or rectal temperature and weather variables were evaluated.

Results—Nasal submucosal and rectal temperatures were related to all weather variables monitored. A positive relationship was determined for ambient temperature and THI with both nasal submucosal and rectal temperatures. A negative relationship was evident for nasal submucosal and rectal temperature with relative humidity, wind speed, and relative barometric pressure. Nasal submucosal and rectal temperatures increased with increasing severity of LWSI category.

Conclusions and Clinical Relevance—Effects of environmental conditions on thermoregulation in calves exposed to extreme heat were detected. The positive relationship between nasal submucosal temperature and ambient temperature and THI raised concerns about the efficacy of intranasal administration of temperature-sensitive modified-live virus vaccines during periods of extreme heat. Environmental conditions must be considered when rectal temperature is used as a diagnostic tool for identifying morbid cattle. (*Am J Vet Res* 2014;75:296–300)

Economic losses as a result of reduced productivity in cattle occur when animals are outside their thermal comfort zone. Heat stress has been estimated to cause annual losses of $282 million in beef finishing cattle because of reduced dry-matter intake, decreased growth rate, and increased risk of death.[1] In addition, cattle responses to high ambient temperature and relative humidity can mimic the clinical signs of respiratory disease. Heat

	ABBREVIATIONS
LWSI	Livestock weather safety index
THI	Temperature-humidity index

stress has been associated with increased respiratory rate and effort, decreased feed intake, decreased activity, and increased body temperature.[2,3] The similarity in behavior between calves affected by heat stress and cattle with respiratory disease can create challenges for people responsible for monitoring animal health.

The THI, which was established to estimate the severity of risk from heat stress in cattle, is based primarily on ambient temperature and relative humidity.[4,5] The THI is used in the LWSI to categorize environmental conditions: normal (THI, ≤ 74), alert (75 to 78), danger (79 to 83), and emergency (≥ 84).[6,7] The LWSI was established by the USDA Agriculture Marketing Service to provide recommendations for transportation of cattle and swine during extreme summer conditions.[7] Ambient temperature and relative humidity have been positively correlated with panting scores in cattle during hyperthermal conditions.[4]

Although thermography measurement of nares temperature in cattle has been discussed,[8–10] no study has been conducted to determine the effect of environmental temperature on nasal submucosal temperatures. Nares thermography records the temperature of the air exiting the nasal passages. These measurements are subject to errors associated with the conditions in which the thermography images are obtained. Also, thermography equipment of sufficient quality to accurately measure these temperatures is expensive.

Current use of temperature-sensitive vaccines administered via the intranasal route requires that nasal mucosal temperatures do not exceed 39°C.[11] To the authors' knowledge, the effect of extreme summer environmental conditions on nasal submucosal temperature has not been reported. The objective of the study reported here was to determine the effect of ambient temperature, relative humidity, wind speed, relative barometric pressure, and THI on nasal submucosal and rectal temperatures in cattle during extreme summer heat conditions. This information would be useful for understanding the effects of environment on thermoregulation.

Materials and Methods

Animals—Twenty black crossbred beef heifers with a mean ± SD body weight of 217.8 ± 12.1 kg were selected for the study. All calves were approximately 6 months old. Calves were owned by Kansas State University, and all procedures were approved by an institutional animal care and use committee.

Calves were housed in a single pen (12.2 × 24.4 m) throughout the study. Calves were fed a starter ration that included 2.3 kg of corn/d with trace minerals and 0.9 kg of alfalfa/d. In addition, calves had ad libitum access to brome hay, a salt block, and water. A south-facing, open-faced tin shed was available as a source of shade throughout the study. Cattle were humanely handled during each portion of the study and observed twice daily throughout the study to monitor health status.

Measurements were obtained during 3 nonconsecutive intensive 24-hour monitoring periods (measurements obtained for a total of 72 hours). Monitoring periods were selected on the basis of weather forecasts that the ambient temperature would exceed 32.2°C. An intensive monitoring period began at 8 AM, and nasal submucosal and rectal temperatures were recorded every 2 hours for 24 hours. Calves were moved through a chute, and rectal temperatures were measured with a rapid equilibration probe[a] to allow for minimal handling during the measurement period. Commercially available, inexpensive, and easily applied biothermal sensors[b] were implanted in the left and right nasal submucosa approximately 100 mm caudal to the alar cartilages. The biothermal sensors were radiofrequency transponders activated by an electronic recording device and had an accuracy of ± 0.1°C. A remote weather station[c] was placed at the research facility where the calves were housed to enable monitoring of local ambient temperature, relative humidity, wind speed, and relative barometric pressure throughout the study. The weather station was set to record variables for the same time periods during which calves were moving through

the chute. Results for the aforementioned variables were used to calculate THI for each time point by use of the following equation[12,13]:

$$THI = (0.81 \times \text{ambient temperature}) + (\text{relative humidity} \times [\text{ambient temperature} - 14.4]) + 46.4$$

Statistical analysis—Data were imported into a commercial statistical software package[d] for analysis. The mean value for the left and right nasal submucosal temperature was calculated at each time point and used for statistical analysis. Values for weather variables were rounded to the nearest whole number prior to analysis. A multivariate model was created to evaluate the potential relationships for nasal submucosal or rectal temperature with all environmental weather variables (ambient temperature, relative humidity, wind speed, relative barometric pressure, and THI). Individual generalized mixed models were used to evaluate potential relationships between nasal submucosal and rectal temperatures on the basis of ambient temperature, relative humidity, wind speed, relative barometric pressure, and THI. All analyses included a random effect for each calf because of repeated measures on the calves and a random effect for each day (24-hour period of sample collection) temperatures were recorded. The time of day observations were obtained (2-hour intervals) was included as a fixed effect in models whereby the interaction between time and the effect of interest was evaluated or as a random effect in models constructed to evaluate the overall estimates of the amount of time spent in thermal zones. For all comparisons, values of $P < 0.05$ were considered significant. Correlation analysis between rectal temperature and nasal submucosal temperature was performed; this analysis included random effects for repeated measures on calves, study day, and time of day.

The THI was used in the LWSI for categorizing recommendations of transportation of cattle during extreme summer conditions.[7] Nasal submucosal and rectal temperatures were evaluated for each LWSI category with generalized mixed models that included a random effort for repeated measures on calves and a random effect for each day of the study. Student t tests were used to evaluate differences in nasal submucosal and rectal temperatures for each LWSI category. For all multiple comparisons, values of $P < 0.01$ were considered significant.

Results

All calves remained healthy throughout the study, and the ambient temperature exceeded 32.2°C for each of the 24-hour intensive monitoring periods. Sunrise was at approximately 6 AM, and sunset was at approximately 7 PM. Overnight low temperature was 25.5°, 21.4°, and 20.7°C, respectively, for the three 24-hour intensive monitoring periods. Mean environmental conditions by time of day were summarized (**Table 1**). Ambient temperature was lowest in the early morning (6 AM; mean, 22.6°C) and highest in the late afternoon (4 PM; mean, 36.8°C). Relative humidity was highest in the early morning (6 AM; mean, 80.0%) and lowest in the late afternoon (4 PM; mean, 39.7%). Wind speed was lowest in the early morning (8 AM; mean, 1.4 m/s) and highest in the late afternoon (4 PM; mean, 3.8 m/s). Relative baromet-

ric pressure was highest in the midmorning (10 AM; mean, 739.06 mm Hg) and lowest in the late afternoon (6 PM; mean, 736.85 mm Hg). The THI was lowest in the early morning (6 AM; mean, 70.96) and highest in the late afternoon (4 PM; mean, 84.69).

During the 72 hours of monitoring, the calves were exposed to environmental conditions in several LWSI categories. The percentage of time the calves spent in each LWSI category was as follows: normal, 27.8%; alert, 13.9%; danger, 25.0%; and emergency, 33.3%.
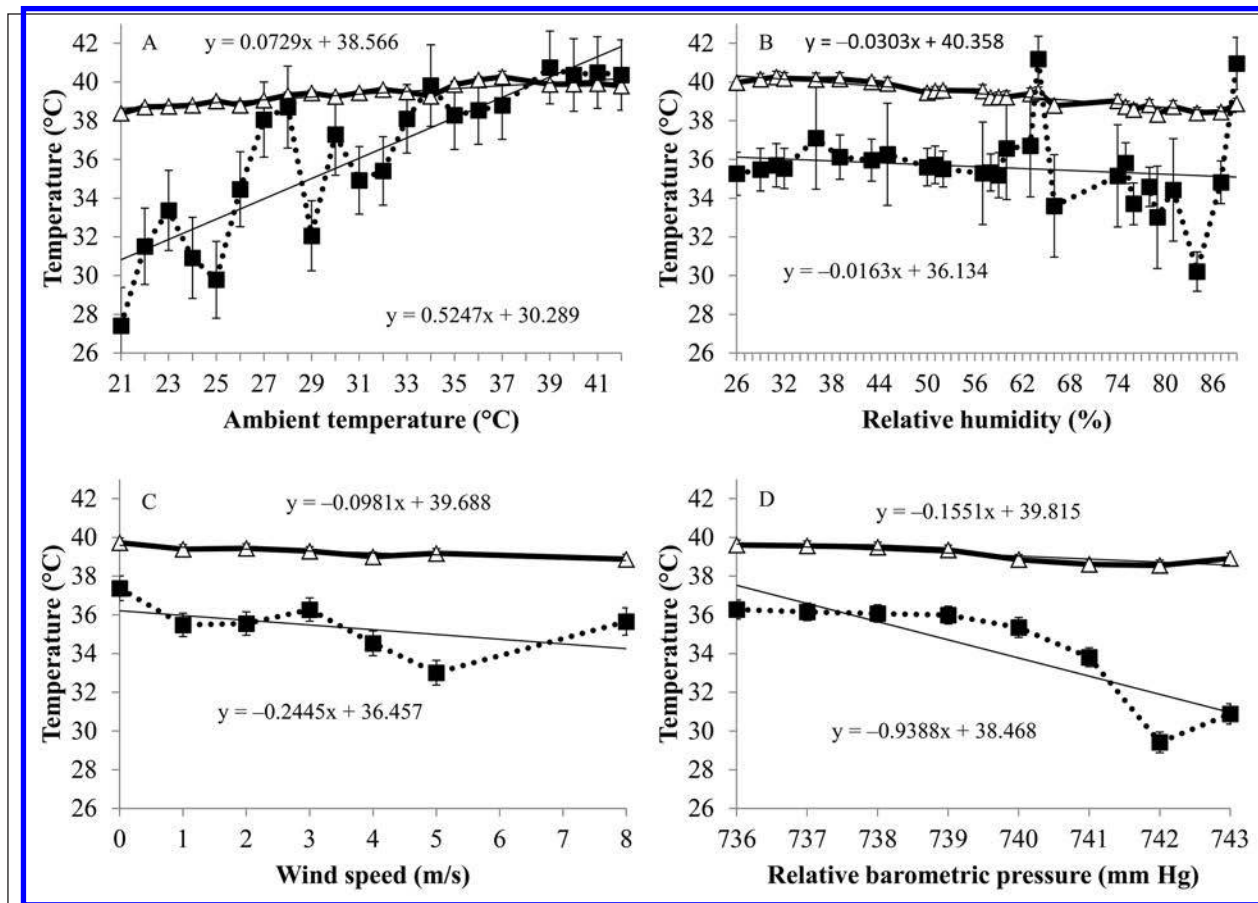

Figure 1—Mean ± SE rectal temperature (white triangles) and nasal submucosal temperature (black squares) in 20 black crossbred beef heifers as a function of ambient temperature (A), relative humidity (B), wind speed (C), and relative barometric pressure (D) during extreme summer weather conditions. The line of best fit and equation for that line were determined for nasal submucosa temperature (bottom equation in each panel) and rectal temperature (top equation in each panel). Data were obtained during 3 nonconsecutive 24-hour periods when ambient temperature was forecasted to exceed 32.2°C. The model used for analysis included effects for repeated measures on individual calves, repeated measures on study day, and time of day. All weather variables monitored had significant ($P < 0.01$) effects on rectal temperature and nasal submucosal temperature.

Table 1—Mean ± SD rectal temperature and nasal submucosal temperature by time of day in 20 black crossbred beef heifers exposed to extreme environmental conditions in summer.

Time of day	Ambient temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Relative barometric pressure (mm Hg)	THI	Rectal temperature (°C)	Nasal submucosal temperature (°C)
8 AM	28.9 ± 3.7	66.7 ± 11.9	1.4 ± 0.4	738.97 ± 0.94	79.1 ± 3.5	39.10 ± 0.47	36.3 ± 1.3
10 AM	34.2 ± 3.3	53.0 ± 12.2	1.8 ± 0.1	739.06 ± 0.94	84.2 ± 1.8	39.58 ± 0.58	37.9 ± 0.6
Noon	35.5 ± 3.9	47.3 ± 11.2	1.8 ± 0.8	738.72 ± 1.05	84.7 ± 2.7	39.64 ± 0.63	37.5 ± 0.6
2 PM	36.7 ± 4.1	41.7 ± 8.3	2.4 ± 0.6	738.12 ± 1.04	85.1 ± 3.4	39.70 ± 0.70	37.0 ± 0.6
4 PM	36.8 ± 4.1	39.7 ± 10.2	3.8 ± 3.0	737.53 ± 1.05	84.7 ± 2.8	40.05 ± 0.70	36.6 ± 0.8
6 PM	35.9 ± 3.8	41.3 ± 9.5	3.3 ± 1.5	736.85 ± 0.95	84.0 ± 2.8	39.90 ± 0.57	35.3 ± 0.8
8 PM	32.4 ± 2.9	52.0 ± 9.3	2.1 ± 1.0	737.28 ± 1.54	81.8 ± 2.3	39.71 ± 0.51	34.7 ± 0.9
10 PM	27.4 ± 3.6	61.7 ± 12.3	3.2 ± 1.3	738.12 ± 2.02	76.2 ± 3.3	39.25 ± 0.54	34.7 ± 1.6
Midnight	25.8 ± 3.3	68.7 ± 11.9	2.1 ± 1.0	738.04 ± 1.19	74.7 ± 3.4	38.99 ± 0.47	34.5 ± 1.3
2 AM	24.8 ± 2.3	72.3 ± 11.0	1.6 ± 0.3	738.38 ± 2.00	73.8 ± 2.2	38.86 ± 0.49	34.4 ± 1.7
4 AM	23.6 ± 2.7	76.3 ± 13.1	1.6 ± 0.7	738.89 ± 2.91	72.3 ± 2.8	38.73 ± 0.43	34.1 ± 2.7
6 AM	22.6 ± 2.1	80.0 ± 11.4	2.7 ± 2.2	739.06 ± 2.24	71.0 ± 2.3	38.56 ± 0.38	33.9 ± 3.2

The model used for analysis included effects for repeated measures on individual calves for rectal temperature and nasal submucosal temperature and repeated measures on study day. Time of day had a significant ($P < 0.01$) effect on all variables evaluated.
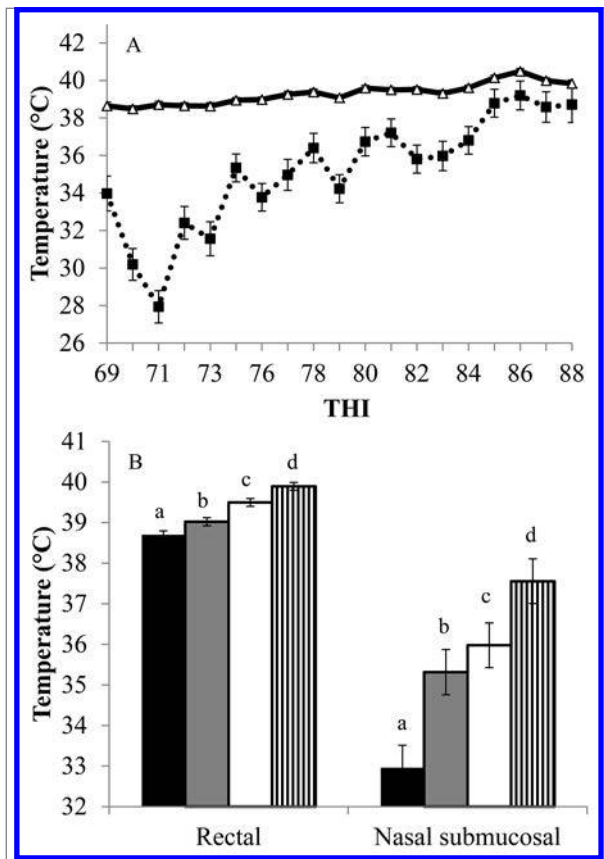
Figure 2—Mean ± SE rectal temperature (white triangles) and nasal submucosal temperature (black squares) in 20 black cross-bred beef heifers as a function of THI (A) and mean ± SE rectal temperature and nasal submucosal temperature by LWSI category (B). In panel A, the THI had a significant ($P < 0.01$) effect on rectal temperature and nasal submucosal temperature. In panel B, the THI was used in the LWSI to categorize environmental conditions as follows: normal (THI, ≤ 74 [black bars]), alert (THI, 75 to 78 [gray bars]), danger (THI, 79 to 83 [white bars]), and emergency (THI, ≥ 84 [vertical-striped bars]).[6,7] [a–d]Within a temperature variable, LWSI categories with different letters differ significantly ($P < 0.01$). Notice that the scale on the y-axis differs between the panels.

A single multivariate model for comparing nasal submucosal or rectal temperature with all of the weather variables did not converge; therefore, results were reported for models created to evaluate relationships between nasal submucosal or rectal temperatures and individual weather variables. Nasal submucosal and rectal temperatures were significantly ($P < 0.01$) associated with ambient temperature, relative humidity, wind speed, relative barometric pressure, and time of day (**Figure 1**; Table 1). Nasal submucosal and rectal temperatures were significantly ($P < 0.01$) associated with THI (**Figure 2**). Rectal and nasal submucosal temperatures increased with increasing severity of LWSI category. Analysis revealed that there was a correlation ($r^2 = 0.77$) between nasal submucosal and rectal temperatures. Nasal submucosal temperature exceeded 39°C in 5 calves during the monitoring period.

Discussion

In the study reported here, nasal submucosal and rectal temperatures in beef heifers were correlated with weather variables during periods of extreme heat. This may be of importance when evaluating the response of cattle to intranasal administration of temperature-sensitive vaccines. Temperature-sensitive vaccines are inactivated at temperatures > 39°C.[11] In the present study, calves exposed to extremely high ambient temperatures occasionally had nasal submucosal temperatures above this threshold. Nasal submucosal and rectal temperatures were strongly correlated. Nasal submucosal and rectal temperature measurements are not subject to human error and may provide a more accurate reflection of temperatures to which the nasal mucosa is subjected, compared with the accuracy for temperatures measured with nasal thermography.

Rectal temperatures are a common component of health monitoring protocols.[14] However, information on the evaluation of the environmental effects on rectal temperatures during conditions of extreme heat or a high THI is lacking. Diurnal variation in rectal temperature of cattle has been described.[15,16] In one of those studies,[15] the lowest rectal temperatures were recorded during the morning hours, and the highest rectal temperatures were recorded during the late afternoon and early evening hours. The diurnal variation was attributed to changes in the environmental conditions those calves were exposed to throughout the day.[15]

In the present study, associations were detected between nasal submucosal and rectal temperatures and all weather variables monitored; however, changes in nasal submucosal and rectal temperatures were more dramatic with increases in ambient temperature and THI. Nasal submucosal temperature increased more rapidly than did rectal temperature with increases in ambient temperature and THI, but there was marked variation. However, the overall pattern was a positive relationship (increases in nasal submucosal and rectal temperatures with increases in ambient temperature and THI). The rectal temperatures in the present study were recorded during summer environmental conditions, which limited interpretation of the data during these summer conditions. These results may prove useful in future studies on extreme heat in the Midwest, which is the location for most beef feedlots.[17,18]

Surprisingly, a slight negative relationship was found for nasal submucosal and rectal temperatures with relative humidity. As relative humidity increases, respiration rates increase in an attempt to dissipate body heat.[4,19] However, the calves in our study were exposed to weather conditions that resulted in an inverse relationship between ambient temperature and relative humidity because the highest relative humidity was detected during the night and the lowest relative humidity was detected during the day. We did not have enough data points to compare animal responses to different amounts of relative humidity at similar ambient temperatures to separate the effects of relative humidity and ambient temperature. The relationship between nasal submucosal temperature and relative humidity was unclear because of the variation in nasal submucosal temperature, which resulted in no pattern that was clearly evident.

Nasal submucosal and rectal temperatures decreased with increases in wind speed, as expected. Wind may help cattle dissipate heat and allow them to thermoregulate more efficiently through evaporation.[20]

It has been suggested that the THI is the best, simplest, and most practical method used to predict risk of heat stress in cattle. The positive relationship for nasal submucosal and rectal temperature with THI was expected. Variation in the nasal submucosal temperature with changes in THI was not as great as the variation in the nasal submucosal temperature with changes in ambient temperature. Both nasal submucosal and rectal temperatures plateaued at a THI ≥ 86. This plateau may be the tolerance limit for nasal submucosal and rectal temperatures in healthy cattle during periods of extreme heat. It could be speculated that cattle would succumb to heat stress at a THI above this threshold, but such studies might endanger the well-being of cattle and have not been performed to the authors' knowledge.

The calves remained healthy throughout the present study. The heifers were monitored continuously, and none of them developed clinical signs of illness throughout the study. The physiologic capability of morbid animals to thermoregulate during periods of extreme heat conditions remains unclear. Heat stress environmental indices have been established that incorporate both solar radiation and wind speed.[21] Intensity of solar radiation was not monitored during the present study, but all calves were housed in a single pen with full exposure to sunlight, although an open-faced tin shed did provide shade.

A diurnal pattern in nasal submucosal and rectal temperatures was detected, but the changes were less marked than in other studies.[15,16] The minimal diurnal fluctuation in the present study may have been related to the environmental conditions to which the calves were exposed. It is important to consider the time of day when rectal temperature is measured and used as a diagnostic tool, given that a change in rectal temperature of 1°C may result in a different diagnosis or treatment.

Limitations of the study included that all monitoring periods were during extreme summer heat and that the weather variables monitored were neither independent of each other nor controlled. We attempted to develop a multivariate model with all of the weather variables included, but it was not possible to create a final model with these data because of convergence issues. Data were collected during three 24-hour periods; however, these periods did not provide sufficient variation among weather and outcome variables to enable us to evaluate them in a single model. A larger data set with increased variation in environmental variables may enable researchers to generate a multivariate model and provide more insights into the true relationships between weather conditions and homeostasis in cattle. Additional studies need to be performed to determine the clinical implications of extreme summer conditions on monitoring, health, productivity, and management strategies of beef calves.

In the present study, weather conditions impacted thermoregulation in cattle. Overall, calves were efficient at responding to various extremes of ambient temperature and relative humidity. The positive relationship between nasal submucosal temperature and ambient temperature and THI raises concerns about the efficacy of intranasal administration of temperature-sensitive modified-live virus vaccines to cattle during periods of extreme heat. Environmental conditions and the THI need to be considered when rectal temperature is used as a diagnostic tool to identify morbid animals because weather variables are associated with rectal temperature.

References

1. St-Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by US livestock industries. *J Dairy Sci* 2003;86(suppl 1):E52–E77.
2. Mitlöhner FM, Morrow JL, Dailey JW, et al. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *J Anim Sci* 2001;79:2327–2335.
3. Fuquay JW. Heat stress as it affects animal production. *J Anim Sci* 1981;52:164–174.
4. Mader TL, Davis MS, Brown-Brandl T. Environmental factors influencing heat stress in feedlot cattle. *J Anim Sci* 2006;84:712–719.
5. Mader T, Griffin D, Hahn L. *Managing feedlot heat stress*. Lincoln, Neb: Cooperative Extension University of Nebraska-Lincoln, 2000.
6. Hahn GL, Gaughan JB, Mader TL, et al. Thermal indices and their applications for livestock environments. In: *Livestock energetics and thermal environmental management*. St Joseph, Mich: American Society of Agricultural Engineers, 2009;113–130.
7. USDA Agricultural Marketing Service. *Cattle and swine trucking guide for exporters*. Washington, DC: USDA, 1999.
8. Reid ED, Fried K, Velasco JM, et al. Correlation of rectal temperature and peripheral temperature from implantable radio-frequency microchips in Holstein steers challenged with lipopolysaccharide under thermoneutral and high ambient temperatures. *J Anim Sci* 2012;90:4788–4794.
9. Theurer ME, White BJ, Anderson DE, et al. Effect of transportation during periods of high ambient temperature on physiologic and behavioral indices of beef heifers. *Am J Vet Res* 2013;74:481–490.
10. Theurer ME, Anderson DE, White BJ, et al. Effect of *Mannheimia haemolytica* pneumonia on behavior and physiologic responses of calves during high ambient environmental temperatures. *J Anim Sci* 2013;91:3917–3929.
11. Mills J, Chanock RM, Nusinoff SR, et al. Temperature-sensitive mutants of influenza virus. I. Behavior in tissue culture and in experimental animals. *J Infect Dis* 1971;123:145–157.
12. Hahn GL. Dynamic responses of cattle to thermal heat loads. *J Anim Sci* 1999;77(suppl 2):10–20.
13. Thom EC. The discomfort index. *Weatherwise* 1959;12:57–61.
14. Radostits O. Control of infectious diseases in food-producing animals. *Herd health: food animal production medicine*. 3rd ed. Philadelphia: WB Saunders Co, 2001;147–188.
15. Hanzlicek GA, White BJ, Mosier D, et al. Serial evaluation of physiologic, pathological, and behavioral changes related to disease progression of experimentally induced *Mannheimia haemolytica* pneumonia in postweaned calves. *Am J Vet Res* 2010;71:359–369.
16. Davis MS, Mader TL, Holt SM, et al. Strategies to reduce feedlot cattle heat stress: effects on tympanic temperature. *J Anim Sci* 2003;81:649–661.
17. Feuz DM, Umberger WJ. Beef cow-calf production. *Vet Clin North Am Food Anim Pract* 2003;19:339–363.
18. Mintert J. Beef feedlot industry. *Vet Clin North Am Food Anim Pract* 2003;19:387–395.
19. Seath DM, Miller GD. The relative importance of high temperature and high humidity as factors influencing respiration rate, body temperature, and pulse rate of dairy cows. *J Dairy Sci* 1946;29:465–472.
20. Stokka GL, Smith J, Kuhl G, et al. Heat stress in feedlot cattle. *Compend Contin Educ Pract Vet* 1996;18:S296–S302.
21. Mader TL, Johnson LJ, Gaughan JB. A comprehensive index for assessing environmental stress in animals. *J Anim Sci* 2010;88:2153–2165.