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Prediction of rectal temperature using non-invasive physiologic variable measurements in hair pregnant ewes subjected to natural conditions of heat stress

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ABSTRACT

Rectal temperature (RT) is the foremost physiological variable indicating if an animal is suffering hyperthermia. However, this variable is traditionally measured by invasive methods, which may compromise animal welfare. Models to predict RT have been developed for growing pigs and lactating dairy cows, but not for pregnant heat-stressed ewes. Our aim was to develop a prediction equation for RT using non-invasive physiological variables in pregnant ewes under heat stress. A total of 192 records of respiratory frequency (RF) and hair coat temperature in various body regions (i.e., head, rump, flank, shoulder, and belly) obtained from 24 Katahdin × Pelibuey pregnant multiparous ewes were collected during the last third of gestation (i.e., d 100 to lambing) with a 15 d sampling interval. Hair coat temperatures were taken using infrared thermal imaging technology. Initially, a Pearson correlation analysis examined the relationship among variables, and then multiple linear regression analysis was used to develop the prediction equations. All predictor variables were positively correlated ($P<0.01$; $r=0.59$–0.67) with RT. The adjusted equation which best predicted RT ($P<0.01$; $R^2_{adj}=56.15\%$; CV$=0.65\%$) included as predictors RF and head and belly temperatures. Comparison of predicted and observed values for RT indicates a suitable agreement ($P<0.01$) between them with moderate accuracy ($R^2_{adj}=56.15\%$) when RT was calculated with the adjusted equation. In general, the final equation does not violate any assumption of multiple regression analysis. The RT in heat-stressed pregnant ewes can be predicted with an adequate accuracy using non-invasive physiologic variables, and the final equation was: RT=35.57+0.004 (RF)+0.067 (heat temperature)+0.028 (belly temperature).

1. Introduction

Environmentally induced heat stress can provoke problems such as fetal intrauterine growth retardation by limiting development and growth of the placenta in sheep (McCrabb and Bortolussi, 1996). In this sense, detection of heat stress in pregnant ewes is very important to implementation of strategies to mitigate heat stress, and to avoid a reduction in ewe productivity.

Rectal temperature (RT) is a physiological variable widely used to determine the thermal body status of sheep in warm climates (Marai et al., 2007). However, the common technique used (i.e., inserting a lubricated thermometer into the rectum) is invasive and can compromise animal welfare, which becomes more severe during pregnancy. This procedure might also influence the behavior of pregnant ewes, and consequently, true RT (Roberto and Souza, 2014).

Development of RT prediction equations from physiological variables obtained by non-invasive methods could be an alternative to avoid animal stress. Chung et al. (2010), Martello et al. (2010) and Niedermann et al. (2014) developed RT predictive models from body temperatures using some skin regions in swine, dairy cattle and humans, respectively. For instance, Chung et al.

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(2010) reported that RT in pigs could be predicted from skin temperature of the central abdomen, central dorsum and perianal, and Martello et al. (2010) found that skin temperatures of the internal base of tail, vulva and auricular were good predictors of RT in lactating dairy cows. It should be highlighted that no study was found on development of prediction models of RT in pregnant or non-pregnant ewes maintained in warm climates. The objective was to develop a prediction equation for rectal temperature using physiological variables collected via a non-invasive method in hair-breed pregnant ewes maintained in an outdoor environment which would induce heat stress.

2. Materials and methods

2.1. Study site

The study was completed during summer at the Sheep Experimental Unit of the Instituto de Ciencias Agrícolas, Universidad Autónoma de Baja California in the state of Baja California, México. Summer weather in the Mexicali Valley is arid and dry, with extreme daytime high temperatures to 50 °C (García, 1985).

2.2. Data

All procedures involving ewe management were performed according to guidelines of approved local official techniques of animal care in México (NOM-051-ZOO-1995: Humanitarian care of animals during mobilization). Twenty-four multiparous pregnant ewes from Katahdin x Pelibuey crosses subjected to environmental conditions of thermal stress were used to collect data of RT, respiratory frequency (RF) and hair coat temperatures of the body regions head (HT), shoulder (SBT), right flank (RFT), rump (RUT), and belly (BT). Before handling ewes to measure RT and hair coat temperature during the sampling days, RF was evaluated by counting flank movements during 30 s. These counts were multiplied by two to determine breaths per minute (bpm). After that, ewes were gathered by 15 min in a temporary corral in the shade, and then immobilized to simultaneously measure RT and hair coat temperature. A lubricated digital thermometer (Delta Trak®, Pleasanton, CA, USA) was rectally inserted into each ewe for one minute to measure RT, while hair coat temperatures from each ewe were obtained using thermal imaging, which were taken with an infrared thermal imaging camera (Fluke Ti10, Everett, WA, USA) at a 3-m distance. Captured images were downloaded to a computer to be analyzed with the Fluke SmartView® 3.9 software. The average temperature from each coat region (i.e., head, shoulder, right flank, rump, belly) was recorded. All physiological measurements were collected during morning (07:00 h) and afternoon (17:00 h) at days 100, 115, 130 and 145 of gestation. In general, the experimental period was considered as the last third of gestation of ewes (i.e., day 100 to lambing), which was the heart of the summer season, from July 4 to August 24 (2012).

Climatic variables such as temperature (T), relative humidity (RH), wind speed and solar radiation were recorded each hour during the experiment using data of a climatic station (Davis Instruments, model Vantage PRO2™) located 1 km from the study site. The T and RH information was used to calculate the temperature–humidity index (THI) using the formula (Hahn, 1999):

$$THI = 0.81 \times T + RH(T - 14.4) + 46.4$$

Finally all climatic variable daily averages were calculated, as well as maximum and minimum values. The climatic station recorded *T*, RH, wind speed and solar radiation with an accuracy of 0.1 °C, 1%, 0.4 m/s and 1.0 W/m^2, respectively.

2.3. Animals and management

At the beginning of the experiment, ewes had a body weight of 51.1 ± 3.5 kg, and a body condition score of 3.0 ± 0.3 units (5-point scale; 1 = emaciated to 5 = fat; Russel et al., 1969). Ewes were confined to two corrals of 25 m^2 (5 × 5 m) each (n = 12 ewes/pen and 2.08 m^2/ewe), which had waterers that provided drinking water, feeding troughs and shade made of galvanized metal sheets in the center of each corral (12.5 m^2 and 1.04 m^2/ewe) at 2.5 m height. Ewes were fed *ad libitum* with a diet formulated to meet daily nutritional requirements for pregnant ewes during the last third of gestation (Metabolizable energy = 2.4 Mcal/kg of dry matter (DM) and CP = 12% of DM; NRC, 2007). The diet was offered twice per day (08:00 and 18:00 h) and the water availability was free choice. Ingredients of the diet (DM) were 40% wheat straw, 32% wheat grain, 13% cottonseed, 9% cane molasses, 4% soybean meal, 1% limestone, 0.5% minerals and vitamin premix, 0.3% calcium phosphorus, and 0.2% salt.

2.4. Data analysis

A total of 192 observations of each physiologic variable were collected during the experiment and subjected to statistical analysis with the SAS (2004) statistical program. Descriptive statistics and Pearson correlation analysis were developed initially using the procedures PROC MEANS and PROC CORR, respectively. Considering RT as the dependent variable and the rest (i.e., RF, HT, RUT, RFT, SBT, BT) as predictors, multiple linear regression (MLR) analyses were completed to obtain the prediction equation using the PROC REG procedure. Independent variables included in the final equation were selected using stepwise regression. The model was adjusted across residual analysis, and outliers and influential data points were identified and deleted when the value of two or more indicators (i.e., RS Student, Leverage, DFFITS, COV RATIO and DFBETAS) in a single observation were out of range (Myers, 1990). Regression analyses were completed again after elimination of an observation and the goodness of fit of the models were verified by examining the adjusted coefficient of determinations (R^2_{adj}), root means square error (RMSE), CV, test of Durbin Watson (DW), variance inflation factor (VIF) and tolerance (TOL). If the parameters of the regression model were improved after initial removal of an outlier, then it was removed from the dataset. This procedure was repeated for each outlier until the model had absence of lack of fit.

Finally, accuracy of the adjusted model to predict RT was evaluated and validated through an univariate linear regression analysis comparing predicted and observed values. Additionally, plots of residuals (i.e., observed–predicted and studentized) as a function of the estimated RT with the final model were completed. It was assumed that the best model to predict RT had the highest R^2_{adj} but the lowest RMSE, CV, and mean of residuals (around 0), suitable values of VIF and TOL, as well as no violation of regression assumptions.

3. Results

3.1. Climatic conditions and physiological variables

Daily averages of temperature, relative humidity, THI, wind speed and solar radiation recorded during the experiment were 34.3 °C, 44.2%, 82.6 units, 2.8 m/s and 504.7 W/m^2, respectively (Table 1). The ambient temperature ranged from 26 to 42 °C and the THI from 76 to 88 units. The ewes had an average RT and RF of 39.6 ± 0.4 °C and 116.6 ± 31.6 bpm, respectively. Mean values of