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Thermoregulatory Mechanisms of Jersey Adult Cattle and Calves Based on Different Body Sites Temperature

Research Article

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ABSTRACT

In this experiment six healthy adult dairy Jersey cattles and eight calves (aged 4-6 months) were selected to measure temperature of different body skin sites, rectal temperature, respiration and heart rates during summer and winter. Body sites maximum and minimum temperature in calves during summer belonged to the ear, forehead, right flank, abdomen (38.4-38.9 ˚C) and carpus (32 ˚C). This was also true for the foreleg, abdomen, tail (38-38.15 ˚C) and tarsus (33.9 ˚C) of cattle, respectively. The minimum body temperature of all these animals was detected in the carpus and tarsus. Correlation coefficient was significant between rectal and tail temperatures (r=0.61; P<0.01). Also, there was significant correlation of respiration rate with abdomen, dewlap, neck, tail and rump temperature, but maximum coefficients were related to respiration rate with ear, forehead and tail temperature (r=0.8-0.91; P<0.01). Heart rate had maximum correlation with ear and forehead as well. It is concluded that both abdomen and tail and also other body sites, such as ear and neck, had significant role in body heat loss. Cattle heat dissipation to the environment is through the skin of their tail and ear and these have a higher correlation with respiration, heart rate and rectal temperature.

KEY WORDS cattle, heat stress, skin temperature, thermoregulatory.

INTRODUCTION

Tropical regions have a long period of heat stress and this challenge confronts dairy cattle production with a big problem. Heat stress is a major factor involved in reducing productivity and animal development. If animals experience thermal discomfort, they seek the ways to lose heat and this involves a series of adaptations of the respiratory, circulatory, excretory, endocrine and nervous systems. These characteristics of adaptation can determine the tolerance of each breed to its environment. Potential thermal stress tolerance varies among species, breeds and individuals and within the same breed (Das *et al*. 1999; West, 2003; West *et al*. 2003; Nonaka *et al*. 2008; McManus *et al*. 2009; Martello *et al*. 2010). The effects of heat stress are higher in cattle than in other ruminant due to their higher metabolic rate and poorly developed water retention in the kidney and gut. With an increased water intake as a mechanism to cope with heat stress, and a higher excretion of water through sweating and panting, the body water content and mineral concentrations can be disturbed. Cattle can, within limits, adapt it self to environmental challenges to minimize adverse consequences. However, at temperatures above 25 ˚C feed intake drops (Titto *et al*. 2011; Geraldo *et al*. 2012; Titto *et al*. 2013). It is known that a rise in rectal temperature indicates that the heat loss mechanisms of the animals are unable to cope with increasingly hot environmental conditions. Increasing environmental warmth or heat factors cause increases in rectal temperature and decreases in feed intake (Brown-Brandl *et al.* 2003; Correa-Calderon *et al.* 2004).

Heat tolerance is considered to be one of the most important adaptive aspects for cattle. Lack of thermally-tolerant breeds of cattle has already been a major constraint on production in the world. The basic thermoregulatory strategy of a mammal is to maintain a body core temperature greater than the environmental temperature to allow heat to flow out from the core (Brown-Brandl *et al.* 2005). The heat loss occurs by conduction, convection, radiation and evaporation. The first three ways are thermal gradient dependents and are effective in keeping body heat in equilibrium with the environment (Correa-Calderon *et al.* 2004).

It was suggested that mechanisms linked to thermal exchange are more associated with the body surface temperature. These mechanisms could be due to the fact that body temperatures taken closer to external surface are more subject to the influence of environmental temperatures and therefore are less stable than deeper body temperatures such as rectal one. Additionally, a linear association between body skin temperature and respiration rate was observed, indicating that increases in body skin temperature led to the activation of the thermoregulation mechanisms (increase in respiration rate) in order to maintain the body temperature. This process could be effective to keep the body temperature within the normal range (Umphrey *et al.* 2001).

Heat stress causes changes in the homeostasis process and has been quantified by measurements of physiological variables like rectal temperature and respiratory frequency. Measurement of the temperature at alternative body sites also showed a good direction in heat stress evaluation in cattle (Martello *et al.* 2010).

In cattle reared at two different temperatures (cool and hot) and then shifted to a hotter environment, it was observed that the group reared at hot temperatures showed less response to thermal stress than the ones which was reared under cool conditions (Kendall *et al.* 2006). The smaller the body, the higher possibility of heat loss. It is because of a high surface area to volume ratio that heat loss occurs at much higher level.

The number of physiological and behavioral responses of Jersey cattle during summer and winter is just interesting because of their small body bulk. However, information on body surface temperature changes during summer and winter, during solar radiation exposure in Jersey cattle is not available. The thermoregulatory mechanisms of Jersey cattle have been the aim of this study.

MATERIALS AND METHODS

In this experiment six healthy adult dairy Jersey cattle and eight calves (aged 4-6 months) were selected in order to be measured by temperature of different body skin sites, rectal temperature, respiration and heart rate during summer and winter in the research station of the University of Jiroft (Iran; 28˚ north latitude and 57˚ east Longitude with 712 m altitude). Weather and temperature-humidity index (THI) information of different months are presented in Table 1. These animals were kept in an open area of a three-wall building and a feed bunk with shelters orientated north-south. The height of the shade structures ranged from 4.2 to 5.6 m. The area of the provided shade was between 3.2 and 3.6 m^2. Selected animals and all cattle within the area were able to access the shade at the same time. Their diet consisted largely of corn silage, dried alfalfa, wheat bran, and mineral stone. They had free access to water and rock salt and were daily fed in the morning and evening. At the hottest hours of the day (14:00-15:00 hours) respiratory rate was measured by observing costal movements and heart rate with a stethoscope within 15 seconds and expressed as rate per min. Body temperature of different sites (carpus, right flank, rump, tail, tarsus, abdomen, dewlap, neck, foreleg, forearm, left flank, ear and forehead) was measured by means of an infrared thermometer (infrared animal thermometer UT900 series model UT932) kept at15cm distance from the skin of hind and forelimbs and other parts of body. THI was calculated with the following equation: (Titto *et al.* 2013):

$$THI= (1.8\times Tdb+32) - (0.55-0.0055\times RH) \times (1.8\times Tdb-26)$$

Where:
Tdb: dry bulb temperature.
RH: relative humidity.

Data were analyzed with SAS software (SAS, 1996). Experimental design consisted of fixed effect of season and animal type (calf and cattle) as a factorial in a completely randomized design. Means were compared according to Duncan test as α=0.05.

$$Y_{ijk}= \mu + S_i + TY_j + (S\times TY)_{ij} + e_{ijk}$$

Where:
Y_{ijk}: each observation.
μ: mean.
S_i: season effect.
TY_j: animal type effect.
(S×TY): interaction between season and animal type.
e_{ijk}: experimental standard error.

RESULTS AND DISCUSSION

Calculated THI based on our weather information was 75, 81.6, 68.5 and 60.6 for spring, summer, fall and winter, respectively.

Table 1 Weather information and thermal humidity index of twelve months of year

Months of year	March	Apr	May	June	July	Aug	Sep	Oct	Numb	Dec	Jun	Feb
Temperature range	18.2 -29.9	24.5 -37.3	29 -41.8	30.7 -43.3	31.6 -43.5	28.5 -41.5	23.3 -35.6	18.4 -29.7	12.1 -21.7	8.2 -18	10.9 -21.5	13.7 -25.9
Temperature mean	24	30.9	35.4	37	37.5	34.8	29.5	24	16.9	13.1	16.2	19.8
Humidity range	24-54	15-40	11-30	17-42	11-31	14-35	16-40	21-49	35-72	32-75	35-74	26-67
Humidity mean	39.1	27.7	20.2	29.9	21.2	24.2	27.9	35	53.7	53.6	54.7	46.7
THI	69.7	76.1	79.5	83.2	81.8	79.69	74.67	69.3	61.49	56.40	60.57	65.04

THI: temperature-humidity index.

The THI is usually classified into classes of below 71 as comfort zone, values ranging from 72 to 79 as mild stress, 80-89 moderate stress and values above 90 as severe stress (Brown-Brandl *et al.* 2005). According to these classifications, fall and summer are considered as seasons without heat stress and spring and winter with mild and moderate heat stress in this experimental zone.

Different body sites and rectal temperatures, heart and respiration rates are summarized in Table 2. All parameters but not rectal temperature were affected by season. Body site maximum and minimum temperature in calves during summer belonged to ear, forehead, right flank, abdomen (38.4-38.9 ˚C) and carpus (32 ˚C); this was also true for foreleg, abdomen, tail (38-38.15 ˚C) and tarsus (33.9 ˚C) for cattle, respectively. Minimum body temperature in all these animals was related to carpus and tarsus. Significant differences ($P<0.01$) between body parts temperature of cattle and calves were related to neck, foreleg and forehead. Of these parameters, the neck and foreleg temperature were significantly higher in cattle ($P<0.01$). Respiration and heart rate of different animals were significantly different seasonally ($P<0.05$). Calves had higher records of respiration and heart rate during both seasons. Also these parameters were higher during summer compared to winter in both categories of animals. Difference between left and right flank temperature of calves during summer and winter was found significantly ($P<0.01$), as right flank temperature of calves was higher than the left oneduring summer (38.4 versus 37.5 ˚C) and vice versa in winter (27.9 *vs*. 30.2 ˚C). Correlation coefficients were significant between rectal and tail temperature ($P<0.01$). Also there was significant correlation of respiration rate with abdomen, dewlap, neck, tail and rump temperature, but maximum coefficients were related to respiration rate with ear, forehead and tail temperature. Heart rate had maximum correlation with ear and forehead temperatures as well (Table 3). The present study has identified physiological parameters of body sites temperature during the hottest hours of the day during summer and winter between Jersey cattle and calves. This information showed that skin temperature changes in different parts of body skin of cattle and calves which were kept in a three-wall, roofed building with an open area equipped with a shelter above feeder and water trough.

Respiration rate

According to Das *et al.* (1999) in buffalo calves, the respiration rate progressively increased to a peak level at 12.00 hour and remained elevated till 17.00 hour and declined thereafter (66-70 breath/min) (Das *et al.* 1999). In our results, Jersey cattle had high respiration rate during heat stress. It is suggested that under heat load conditions, acclimated ruminant increase heat loss with elevated respiration rate.

Also respiration rate of cattle has been reported 33 and 90 breath/min during cool and hot weather conditions (Nonaka *et al.* 2008). In Merino and Omani sheep, respiration rate had an increase of 2-2.5 times between cool and hot seasons but rectal temperature remained the same (Srikandakumar *et al.* 2003).

Normal respiration rate in adult cattle is between 24 and 36 breath/min of respiratory movements per minute. However, it may also vary between 12 and 36 mov/min (McManus *et al.* 2009). Whereas the same author reported that the respiration rate mean of seven breeds of cattle was between 26-38 breath/min.

Controversially, Holstein cattle showed high respiration rate during fall and winter in comparison with dry and rainy summer, despite the fact that they had cooling equipment (Titto *et al.* 2013). The increase in thermoregulatory values, such as respiration rate and heart rate, which could indicate heat stress in animals, was observed in this study and is in accordance with the values previously reported by Das *et al.* (1999).

Body skin temperature

Pattern of surface temperature changes, at different body sites of cattle and calves, was similar to buffalo calves which their skin temperature changes that had happened in relation to the ambient temperature and the hottest hours of a typical day between 1300-1700 hours. Thus, at these hours body skin temperature of buffalo calves was reported 40-46 ˚C (Das *et al.* 1999). But in our experiment, the animals showed skin temperature ranging from 32 ˚C to 38.9 ˚C and 22 ˚C to 31 ˚C in summer and winter, respectively.

The magnitude of changes in body surface temperature belonged to the ear, forehead, abdomen and right flank in calves, and foreleg, tail and abdomen in cattle.

Table 2 Mean ± SD different body sites and rectal temperature, respiration and heart rate of Jersey calves and cattle during summer and winter

Parameters	Calf	Calf	Cattle	Cattle	Season effect	Animal type effect	Interaction between effects
	Summer	Winter	Summer	Winter			
Carpus	32.9±1.86	24.36±0.66	34.45±1.64	22.96±1.19	**	NS	NS
Right flank	38.42±0.36	27.9±0.85	37.6±1.21	30.5±0.80	**	NS	**
Rump	37.57±0.38	30.13±0.90	37.83±1.36	30.0±0.20	**	NS	NS
Tail	35.65±0.99	30.4±1.25	38.1±1.78	27.5±1.11	**	NS	**
Tarsus	33.1±0.67	24.06±0.40	33.98±1.07	24.13±2.83	**	NS	NS
Abdomen	38.5±0.82	29.83±1.89	38.0±0.88	29.67±1.86	**	NS	NS
Dewlap	36.8±1.18	27.26±0.64	37.55±0.86	28.7±1.23	**	NS	NS
Neck	36.97±0.79	30.27±0.65	37.7±0.86	31.33±1.03	**	**	NS
Foreleg	37.05±0.64	28.76±0.55	38.15±1.42	30.23±0.66	**	**	NS
Left flank	37.55±0.25	30.20±1.05	37.45±1.71	29.43±0.95	**	NS	NS
Forearm	35.87±0.74	29.93±1.05	37.63±1.01	28.62±0.98	**	NS	NS
Ear	38.9±0.83	31.4±0.79	37.82±0.70	28.07±1,81	**	NS	NS
Fore head	38.87±0.87	33.06±0.80	37.92±0.62	28.96±1.93	**	**	*
Respiration rate	78.75±7.13	42.33±3.51	67.83±7.19	38.33±5.03	*	**	NS
Heart rate	101.75±12.09	88.0±4.0	96.33±7.81	65.33±11.0	*	**	*
Rectal temperature	40.02±0.86	39.5±0.78	40.05±0.94	38.87±0.61	NS	NS	NS

* (P<0.05) and ** (P<0.01).
NS: non significant.

Table 3 Pearson correlation coefficient between different body sites temperature with rectal temperature, respiration and heart rates

Parameters	Rump	Tail	Tarsus	Abdomen	Dewlap	Neck
Rectal temperature	0.55**	0.61**	0.50**	0.54**	0.53**	0.52**
Respiration rate	0.85**	0.77**	0.59**	0.89**	0.86**	0.83**
Heart rate	0.64**	0.64**	0.57**	0.6**	0.64**	0.57**
	Fore leg	Left flank	Fore arm	Ear	Forehead	Heart rate
Rectal temperature	0.54**	0.55**	0.59**	0.55**	0.57**	0.57**
Respiration rate	0.81**	0.86**	0.8**	0.91**	0.88**	0.62**
Heart rate	0.62**	0.67**	0.68**	0.74**	0.70**	-

** (P<0.01).

However, in buffalo calves, the magnitude of changes in body surface temperature was observed at its maximum at the mid-back and minimum at the mid-neck. Also the difference between maximum and minimum skin temperature of morning and afternoon hours were 13.96 ˚C to 22.33 ˚C (Das *et al*. 1999). According to our results, this difference between summer and winter was 10-15 ˚C.

It is inferred that calves used foremost sites such as ear and forehead. On the other hand, cattle used foreleg and tail. Similar results were observed for abdomen in both of them for heat loss from their body. Moderate to high correlations (0.58-0.88) have been observed between skin surface temperature and heat production in four lactating Holstein cows.

The rear area had the higher temperature while the other portions of trunk had intermediate values and the feet had the lowest (moderate weather 12-22 ˚C and 44-75% humidity) (Montanholi *et al*. 2008). In the current study, the other parts of the trunk were cooler than the rear area of the body of cattle and the head area of calves, probably due to their higher thermal insulation which is directly related to the skin thickness and hair density differences; or just because the rear area is nearer to the rectum.

The feet temperatures were the lowest, around 6.0 ˚C in summer and 15 ˚C in winter, below the usual core body temperature for cattle and calves. Maybe the blood supply to the leg skin decreased substantially in both total and capillary blood flow. Probably a similar peripheral vasoconstriction occurred in the cows of the present study to supply the blood flow demand to the calves forehead and hind area of cattle trunk, which resulted in a decrease of the skin surface temperature of their legs. In Holstein cattle, body surface temperature was reported to be 33.55 ˚C and 33.85 ˚C during winter and summer. Weather temperature in that experiment was 15.48 ˚C during winter and 22.9 ˚C in summer (Titto *et al*. 2011). Summer skin temperature and respiration rate for Holstein cattle ranged 37-37.3 ˚C and 70-79 breath/min. However, rectal temperature remained in 38.4-38.7 ˚C. As it was previously mentioned, correlation of skin temperature with other parameters was not high enough to be of interest. Its correlation with rectal temperature was nearly zero (Umphrey *et al*. 2001).

Rectal temperature

Based on literature surveys, the rectal temperature of 39 ˚C may be considered as the critical temperature above which thermoregulatory and productive functions of the cow could be adversely affected, but a range of 38.5-40.5 ˚C during heat stress of buffalo calves (Das *et al.* 1999) or 39.47-40.55 ˚C (Moons *et al.* 2014) has been reported. Nonaka *et al.* (2008) indicated the high environmental temperature of 28 ˚C tended to increase rectal temperature by 0.2 ˚C and that of 33 ˚C increased by 1.2 ˚C. Similarly for Jersey cattle, there was a difference of 0.5-1.18 ˚C between summer and winter rectal temperatures. Rectal temperature is frequently used as an adaptability index in hot environments as its increase means that heat dissipation mechanisms have become insufficient to maintain homoeothermic. This parameter has a diurnal and seasonal pattern so that the difference for Holstein cattle between morning and afternoon for rectal temperature was 1.4 ˚C and all other breeds had shown differences below 1.1 ˚C with the lowest variation for the Crioulo Lageano breed (0.41) in Brazil (McManus *et al.* 2009). Seasonal pattern of rectal temperature was observed in breeds of sheep (Srikandakumar *et al.* 2003). As temperature increases above thermo-neutrality, rectal temperature showed direct relationship to it. Thus, at an air temperature of 30-34 ˚C its fluctuation was 39.46-40.11 ˚C as well as 84-103 breath/min for respiration rate of cattle (Brown-Brandl *et al.* 2003). These results are similar to ours about cattle and calves during the hottest hours of the day. Nevertheless, Holstein cattle showed same rectal temperature of 38.56 ˚C during all seasons of year with or without cooling system (Titto *et al.* 2013). Nonetheless, weather temperature in that experiment was 15.48 ˚C and 22.9 ˚C during winter and summer, respectively; thus, it is in temperature neutral zone classification and summer THI class belonged to mild stress category. In our experiment, weather temperature was respectively 15.4 ˚C and 36.3 ˚C during winter and summer.

Heart rate

In our results, heart rate was significantly higher during summer. However, for Hereford cattle exposed to solar radiation, heart rate change was not found and their respiration rate and rectal temperature were high (Brosh *et al.* 1998). It has been noted that respiration and sweating are the most efficient forms of heat loss in this species. Heart rate reference value for seven cattle breeds was indicated 50-80 beat/min and their means varying between 62 and 70 beat/min (McManus *et al.* 2009). In our results cattle heart rate was in the range of 96-101 beat/min in summer and 65-88 in winter. A major adaptation to thermal stress is peripheral vasodilation and increased blood flow to accommodate evaporative and convective heat losses. This change was facilitated by higher heart rate. Thereafter, blood flow increased to the skin of the extremities and ears which had relatively little hair cover and a high surface area to volume ratio. These factors increase heat transfer between animal and environment. In Jersey calves and cattle, rectal temperature had significant correlation of 0.57 and 0.62 with heart and respiratory rates, respectively. There was a high correlation between rectal temperature and respiratory rate (0.70) (McManus *et al.* 2009; Martello *et al.* 2010). It means that an increase in rectal temperature was associated with an increase in respiration and heart rate.

CONCLUSION

Also, there was a significant difference between body sites temperature of Jersey calves and cattle during summer and winter but they hold rectal temperature in normal range. Skin temperature increase of calves during summer was related to ear, forehead, right flank, abdomen (38.4-38.9 ˚C) and carpus (32 ˚C); this was also true for foreleg, abdomen, tail (38-38.15 ˚C) and tarsus (33.9 ˚C) for cattle, respectively. Calves mostly applied forelimbs and cattle fore and hind-limbs for heat dispersion. It is concluded calves and cattle used different body sites for cooling.

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