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Physiological Responses and Lactation to Cutaneous Evaporative Heat Loss in *Bos indicus*, *Bos taurus*, and Their Crossbreds

Wang Jian, Yang Ke[1], and Lu Cheng[2],*
Department of Veterinary, Faculty of Animal Science and Technology,
Southwest University, Chongqing, 400700, China

ABSTRACT: Cutaneous evaporative heat loss in *Bos indicus* and *Bos taurus* has been well documented. Nonetheless, how crossbreds with different fractional genetic proportions respond to such circumstances is of interest. A study to examine the physiological responses to cutaneous evaporative heat loss, also lactation period and milk yield, were conducted in Sahiwal (*Bos indicus*, n = 10, 444±64.8 kg, 9±2.9 years), Holstein Friesian (*Bos taurus*, HF100% (n = 10, 488±97.9 kg, 6±2.8 years)) and the following crossbreds: HF50% (n = 10, 355±40.7 kg, 2±0 years) and HF87.5% (n = 10, 489±76.8 kg, 7±1.8 years). They were allocated so as to determine the physiological responses of sweating rate (SR), respiration rate (RR), rectal temperature (RT), and skin temperature (ST) with and without hair from 06:00 h am to 15:00 h pm. And milk yield during 180 days were collected at days from 30 to 180. The ambient temperature-humidity-index (THI) increased from less than 80 in the early morning to more than 90 in the late afternoon. The interaction of THI and breed were highly affected on SR, RR, RT, and ST ($p<0.01$). The SR was highest in Sahiwal (595 g/m^2/h) compared to HF100% (227 g/m^2/h), and their crossbreds both HF50% (335 g/m^2/h) and HF87.5% (299 g/m^2/h). On the other hand, RR was higher in HF87.5% (54 bpm) and both HF100% (48 bpm) and HF50% (42 bpm) than Sahiwal (25 bpm) ($p<0.01$). The RT showed no significant differences as a result of breed ($p>0.05$) but did change over time. The ST with and without hair were similar, and was higher in HF100% (37.4°C; 38.0°C) and their crossbred HF50% (35.5°C; 35.5°C) and HF87.5% (37.1°C; 37.9°C) than Sahiwal (34.8°C; 34.8°C) ($p<0.01$). Moreover, the early lactation were higher at HF100% (25 kg) and 87.5% (25 kg) than HF50% (23 kg) which were higher than Sahiwal (18 kg) while the peak period of lactation was higher at HF100% (35 kg) than crossbreds both HF87.5% and HF50% (32 kg) which was higher than Sahiwal (26 kg) ($p<0.05$). In conclusion, sweating and respiration were the main vehicle for dissipating excess body heat for Sahiwal, HF and crossbreds, respectively. The THI at 76 to 80 were the critical points where the physiological responses to elevated temperature displayed change. (**Key Words:** *Bos indicus*, *Bos taurus*, Crossbreds, Heat Dissipation, Respiration, Sweating, Lactation)

INTRODUCTION

The ability of cattle to maintain body temperature depends on their capacity of thermoregulation based on the balance of heat gain and heat loss through four venues: conduction, convection, radiation, and evaporation (Kadzere et al., 2002). Evaporative cooling by sweating and panting is the most important mechanism for body heat dissipation under elevated hot climates due to the amount of heat accumulated as a result of temperature gradient between the body and environment (Hansen, 2004). However, heat loss by panting becomes effective if the excess heat is not dissipated successfully by sweating and its capacity is impacted by the genetic makeup of cattle. McLean and Calvert (1972) found that 84% of heat was lost by evaporation, of which 65% was lost by sweating and 35% was lost by panting. Cattle utilize evaporative cooling in the form of both sweating and panting in an effort to rid themselves of excess body heat when environmental temperatures begin to temperature and humidity index (THI) of 90 (Koatdoke, 2008).

* Corresponding Author: Lu cheng. Tel: +86-023-6825-1196, Fax: +86-023-6825-1196, E-mail: Lucheng@swu.edu.cn
[1] Tianyou Dairy Production Corporation, Chongqing 401120, China.
[2] Faculty of Biotechnology, Southwest University, Chongqing 400700, China.
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According to Chase (2010), there are three levels of physiological responses to heat when THI increases: vasodilation and respiration rates increase at 72<THI<79, sweating rates and both rectal temperature increases and saliva production at 80<THI<89, and rapid respiration rate also increased at 90<THI<98.

In tropical zones, crossbreeding between *Bos indicus* and *Bos taurus* is a common practice not only to increase production and reproduction but also to maintain thermotolerance of breed (Cunningham and Syrstad, 1987). Comparative studies found that *Bos indicus* are more dependent upon increased sweating to dissipate excess body heat based on higher sweating rates, lower rectal temperature, and lower respiration rate, while *Bos taurus* are more likely to utilize an increase in respiration rates to dissipate heat based on higher respiration rate and higher rectal temperature (Koatdoke, 2008). However, how crossbreds with different blood fractions respond to such circumstances are of interest based on the different skin morphology was different at crossbred with different level blood fraction between *Bos indicus* and *Bos taurus*. The hypothesis is that crossbreds will respond either towards *Bos indicus* or *Bos taurus* depending on the level of their blood fractions. Other factors that may also influence bovine physiological responses to excess body heat are changes in both skin and rectal temperatures during periods of elevated temperature. The objective of this study was to examine sweating rates, respiration rates, rectal temperatures, skin temperatures and lactation of Sahiwal (*Bos indicus*), crossbreds of 50% HF and 87.5% HF, and 100% HF (*Bos taurus*).

MATERIALS AND METHODS

Forty cows (No pregnant and lactating)—Sahiwal (n = 10, 444±64.8 kg, 9±2.9 years), HF50% (n = 10, 355±40.7 kg, 2±0 years), HF87.5% (n = 10, 489±76.8 kg, 7±1.8 years), HF100% (n = 10, 488±97.9 kg, 6±2.8 years)—were allocated into the measurement of physiological responses during March-April 2012 at tropical zone. Uniform cows (lactating) measured lactation period and milk yield during September 2014 to February 2015. Those animals were no different from those used for skin morphological response to cutaneous evaperative heat loss by Jian et al. (2014). Physiological data were conducted at same location, but indoor in the morning and outdoor in the afternoon, continuous one week. Sweating rate (SR), respiration rate (RR), rectal temperature (RT), skin temperature (ST) were measured at 06:00 h, 08:00 h, 09:00 h, 12:00 h, 14:00 h, and 15:00 h. Ambient meteorological data was recorded using dry and wet bulb thermometers from 06:00 h to 15:00 h. Temperature and humidity index was calculated as described by Bohmanova et al. (2007).

Sweating rates were determined by the Cobalt chloride (QRëC, Auckland, New Zealand) disc method of Schleger and Turner (1965) where is the equation,

$$SR\ (g/m^2/h) = 3.8410^4/s$$

Respiration rates were determined by observing and counting the number of flank movements for 60 seconds. Rectal temperature was measured using a digitalized-clinical thermometer, whereas, skin temperature with and without hair-cover skin was measured by an infrared surface thermometer (Everest Interscience Inc., Fullerton, CA, USA).

The experiment was conducted in Balanced Incomplete Block Design. The observations were analyzed using analysis of variance (Steel and Torries, 1980). The statistical model was:

$$Y_{ijkl} = m+T_i+G_j+A_{jk}+E_{ijkl}$$

where T_i is time of the day (i = 1,...,7); G_j is the genetic group (j = 1,...,4); A_{jk} is the effect of animals within group; E_{ijkl} = error. It is an interaction of groups to time of day must be used, together with regressions on air temperature, air humidity and THI values. The experimental procedure of this study was approved by the Animal Ethics Committee of Southwest University, based on the Ethics of Animal Experimentation of The National Research Council of China, No. AESWU 62/2013.

RESULTS

Meteorological data and their effect on physiological responses

Meteorological data of dry-bulb temperature, wet-bulb temperature, relative humidity, and temperature humidity index (THI) were significantly different by time (p<0.01) (Table 1). The THI at early morning was less than 80, increasing after 09:00 h and becoming highest (THI>90) around 15:00 h.

All physiological responses including SR, RR, RT, ST increased as the THI increased, in which the highest response appeared at 15:00 h when THI was highest (THI>90) (p<0.01) (Table 2).

Sweating rates and respiration rates

Sweating rates and respiration rates were significantly different and were affected by interaction between breed and THI (p<0.01). Sweating rate were highest in the Sahiwal, and increased in stepwise fashion from 50%> 87.5%>100% HF (Table 2 and Figure 1a). Meanwhile, crossbreds showed rapid increase in RR when compared to Sahiwal, particularly when THI was higher than 76 (Table 2 and Figure 1b). At THI above 80, the SR of 100% HF and

Table 1. Dry bulb temperature (Tdb), wet bulb temperature (Twb), and temperature humidity index (THI) at the cattle house during the daytime

Item	Time						SEM	p-value
	0600 h	0800 h	0900 h	1200 h	1400 h	1500 h		
Tdb (°C)	22.37^{e}	25.00^{d}	27.96^{c}	34.48^{b}	36.00^{a}	36.51^{a}	0.11	<0.01
Twb (°C)	21.58^{e}	24.36^{d}	27.94^{c}	34.22^{b}	35.19^{b}	36.28^{a}	0.12	<0.01
THI	71.97^{e}	75.65^{d}	80.71^{c}	89.99^{b}	91.68^{a}	93.12^{a}	0.14	<0.01

SEM, standard error of the mean.

THI = (Tdb+Twb)×0.72+41 (Bohmanova et al., 2007).

$^{a, b, c, d, e}$ Means within a row with different superscripts differ ($p<0.01$).

crossbreds seemed to plateau (Figure 1a) whereas the RR increased rapidly (Figure 1b).

Results of this study also revealed the thresholds for both sweating and panting (Figure 1a and 1b). The present study found that sweating increased for all four of the breeds in question as the THI values steadily increased from a starting value of 72 (Figure 1a). The increase in Sahiwal sweating rates was found to be linear as the THI rose from a starting value of 72 and increased to a final value of 93. However, sweating rates for both 50% HF and 87.5% HF did not change at THI values around 76 to 80 (Figure 1a).

Skin temperatures

Skin temperatures both with hair and without hair were significantly different and were affected by interaction of breed and THI (p<0.01). Skin temperatures of both Sahiwal and 50% HF were lower than both 87.5% HF and 100% HF, however skin temperatures of Sahiwal and 50% HF reached 35°C before the 87.5% HF and 100% HF (Table 2 and Figure 2a, 2b). Meanwhile, results showed that the skin temperature for both those areas that either did or did not have hair, increased as the THI increased, and reached 35°C at THI 80.

Rectal temperatures

Rectal temperatures were not significantly affected by interaction between breed and THI (p>0.05) (Table 2), but, RT for both 87.5% HF and 100% HF increased significantly at THI above 90 (Figure 1c).

Milk yield

Milk yield were significantly difference at days from 30 to 180 at HF100%, HF87.5%, HF50% and Sahiwal (p<0.05). the early lactation were higher at crossbred 87.5% (25 kg) than HF50% (23 kg) while the peak period of lactation was higher at HF100% (35 kg) than crossbreds of HF87.5% and HF50% (32 kg) which was higher than Sahiwal (26 kg) (p<0.05), but it was no different at crossbred (Figure 3 and Table 3).

DISCUSSION

Breeds (HF100%, HF50%, HF87.5% and pure Sahiwal) were no different and were affected by interaction of weigh and age (p>0.05). It is possible that less heat dissipate from lower body weight to offset more heat dissipate from young at HF50% (n = 10, 355±40.7 kg, 2±0 years).

THI at early morning was less than 80, increasing after 09:00 h and becoming highest (THI>90) around 15:00 h. It was expected that the following circumstances would produce the following results: No stress (THI<72); vasodilation and increased respiration (72<THI<79); sweating rate increased and saliva production (80<THI< 89); panting and sweating rapidly increased (91<THI<99) (Chase, 2010). It was interesting to observe that physiological responses of the cattle in this study were consistent with that expectation (Table 2).

All physiological responses including SW, RR, RT, ST increased as the THI increased. The highest response appeared at 15:00 h when THI was highest (THI>90). At

Table 2. Physiological responses in *Bos indicus*, *Bos taurus*, and crossbred cattle according to breed, time and interaction of breed and time

Items	Breed						Time (THI)								Time× breed
	Sahiwal	HF50%	HF87.5%	HF100%	SEM	p-value	0600 (72)	0800 (76)	0900 (81)	1200 (90)	1400 (92)	1500 (93)	SEM	p-value	
SR (g/m^{2}/h)	595^{a}	335^{b}	299^{b}	227^{c}	10.2	<0.01	224^{e}	267de	334^{cd}	405^{bc}	454^{ab}	510^{a}	9.27	<0.01	<0.01
RR (bpm)	25^{c}	42^{b}	54^{a}	48^{a}	6.4	<0.01	18^{d}	22^{d}	34^{c}	45^{b}	65^{a}	74^{a}	8.7	<0.01	<0.01
RT (°C)	38.5	38.6	38.8	38.7	0.03	>0.05	37.8^{d}	38.5^{c}	38.6^{c}	38.9^{b}	39.3^{a}	39.3^{a}	0.05	<0.01	<0.01
ST (no hair) (°C)	34.8^{c}	35.5^{b}	37.1^{a}	37.4^{a}	0.6	<0.01	30.0^{d}	34.0^{c}	35.9^{b}	38.6^{a}	38.8^{a}	38.8^{a}	1.3	<0.01	<0.01
ST (hair) (°C)	34.1^{c}	35.5^{b}	37.9^{a}	38.0^{a}	0.99	<0.01	29.0^{d}	32.0^{c}	35.5^{b}	40.5^{a}	41^{a}	40.4^{a}	0.74	<0.01	<0.01

THI, temperature humidity index; HF, Holstein Friesian; SEM, standard error of the mean; SR, sweating rate; RR, respiration rate; RT, rectal temperature; ST, skin temperature.

$^{a, b, c, d, e}$ Means within a row with different superscripts differ ($p<0.01$).

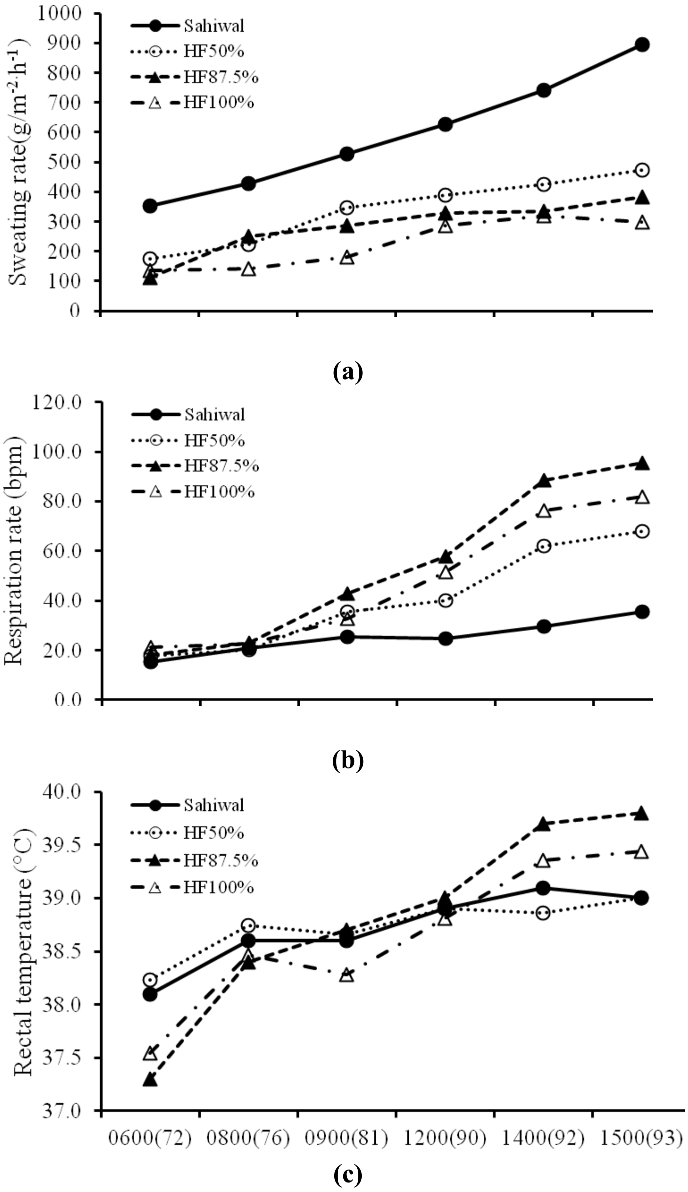

Figure 1. Sweating rate (a), respiration rate (b), and rectal temperature (c) according to THI during 06:00 h to 15:00 h, in Sahiwal, 50% HF, 87.5% HF, and 100% HF. THI, temperature humidity index; HF, Holstein Friesian.

06:00 h, when THI was around 72, the RR was about 18 breaths/min, SR was 224 g/m^2/h, and, most importantly, RT was at the normal range of 37.8°C. This suggested that at 06:00 h the cattle in this study were not under heat stress (Chase, 2010). However, at 09:00 h, when the THI increased up to 80 the RR became 34 breaths/min and skin temperatures increased to 35°C, which suggested an increase of vasodilation at skin (Cunningham, 2002). At the highest THI (>90, 150:00 h) both RR and SR increased prominently and rapidly, and RT at this hour increased to 39.3°C. Thus the observation of the physiological responses that occurred in response to changes in THI was in agreement with those reported by Chase (2010).

Nonetheless, the present study focused on the comparative physiological responses of Sahiwal, 50%, 87.5% and 100% HF. Although the various physiological responses were significantly affected by THI, the result also showed that there was interaction effect between breed and time (THI) on the physiological responses (Table 2). Therefore, not only THI but different breeds were also responsible for any changes observed in SR, RR, RT, and ST.

Sweating rates and respiration rates

Sweating rate was highest in the Sahiwal (Table 2 and Figure 1a). The increasing of SR with the increasing of THI was more prominent in Sahiwal than HF and the crossbreds as supported by the steep slope of the line (Figure 1a). On the other hand, HF and crossbreds showed more rapid increases in RR when compared to Sahiwal, particularly at

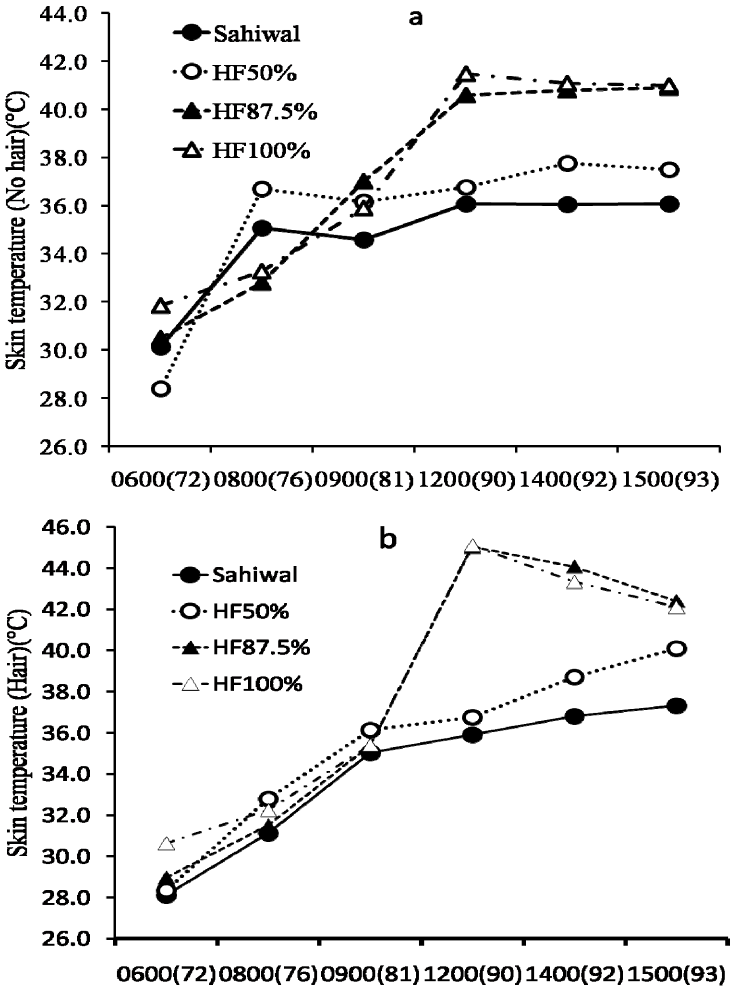

Figure 2. Skin temperature without (a) and with (b) hair according to THI during 06:00 h to 15:00 h, in Sahiwal, 50% HF, 87.5% HF, and 100% HF. THI, temperature humidity index; HF, Holstein Friesian.

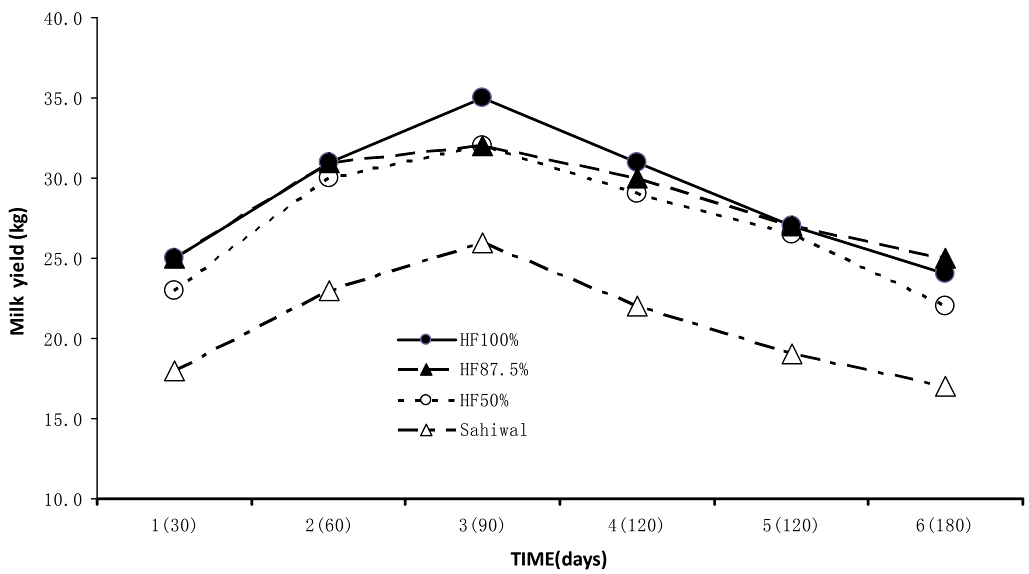

Figure 3. Different milk yield during lactation period from 30 days to 180 days in Sahiwal, 50% HF, 87.5% HF, and 100% HF. HF, Holstein Friesian.

Table 3. Different milk yield mean value during 180 days of Sahiwal (*Bos indicus*), Holstein Friesian (*Bos taurus*), and their crossbred with 50%, 87.5%HF genetic fraction

Days	HF100%	HF87.5%	HF50%	Sahiwal	SEM	p-value
30	25[a]	25[a]	23[b]	18[c]	0.01	<0.03
60	31[a]	31[a]	30[a]	23[b]	0.01	<0.02
90	35[a]	32[b]	32[b]	26[c]	0.06	<0.02
120	31[a]	30[ab]	29[b]	22[c]	0.01	<0.04
150	27[a]	27[a]	26[a]	19[c]	0.01	<0.05
180	24[a]	25[b]	22[b]	17[c]	0.02	<0.05

HF, Holstein Friesian; SEM, standard error of the mean.
[a,b,c] Means within a row with different superscripts are significantly different (p<0.05).

THI higher than 76 (Table 2 and Figure 1b). The prominent response of sweating in Sahiwal (*Bos indicus*) whereas the HF was more reliant upon panting has been previously reported in several studies including from our previous work (Koatdoke, 2008).

At THI above 80, the SR of 100% HF and crossbreds seemed to plateau (Figure 1a) whereas the RR increased rapidly (Figure 1b). This supports the explanation that when cattle facing elevated temperatures, *Bos taurus* and crossbreds with high genetic fraction of HF dissipate the excess heat by panting effectively, complementing this with cutaneous evaporative heat loss if that heat was not dissipated successfully by sweating (Robertshaw, 1985).

The result of this study also revealed the threshold for both sweating and panting (Figure 1a and 1b). The present study found that sweating increased from the beginning of the experiment when THI was 72. The increase in Sahiwal sweating was linear as THI value increased from 72 to 93, however, sweating in both HF50% and HF87.5% did not change at THI around 76 to 80 (Figure 1a). At this particular THI when the sweating of HF and crossbreds seemed to slow down, the respiration sharply increased. This finding is similar to the study of Koatdoke (2008) who reported that sweating rate increased at THI of 72 in *Bos indicus* whereas respiration rate increased at THI 76 in *Bos taurus*.

Skin temperatures

Skin temperatures of Sahiwal and 50% HF were lower than those for both 87.5% HF and 100% HF. However, skin temperatures of both Sahiwal and 50% HF reached 35°C before the 87.5% HF and 100% HF cattle did (Table 2 and Figure 2a, 2b).

Basically, vasodilation is the physiological mechanism that is displayed when cattle are faced with heat stress. A rise in body temperature of only 0.5°C has been shown to cause a sevenfold increase in the skin blood flow in cattle (Cunningham, 2002). Consequently, skin temperature will increase due to the amount of heat that is accumulated at the skin that related to sweat gland components, hair follicles, blood vessels at skin of different breed (Jian, 2014), and both panting and sweating are triggered by an overall increase in the skin temperatures of cattle undergoing heat stress (Gaughan et al., 2000). The present study found that skin temperatures either with hair or without hair increased along with an increase in THI, and reached 35°C at THI 80. The present finding about THI was lower than previously reported for cattle that utilized sweating and panting in an effort to rid themselves of excess body heat when environmental THI exceeded 90 (Beatty et al., 2006; Collier, 2008). The lower threshold for triggering evaporative cooling may be a result from the fact that Sahiwal cattle and their crossbreds have been observed to possess greater thermotolerance than *Bos taurus* breeds and hence are more capable of thriving in a tropical environment. It should also be noted that the skin temperatures of both 100% HF and 87.5% HF were higher than both of 50% HF and Sahiwal at THI above 80 (Table 2 and Figure 2a, 2b).

At THI 80, both ST and RR of 87.5% HF and 100% HF increased accordingly with the plateau of SR, supporting the hypothesis that under heat stress the ST triggers cutaneous evaporative heat loss, and *Bos taurus* and its crossbreds (with high blood fraction) dissipate excess heat effectively via panting when the sweating mechanism has been utilized to the maximum extent that was physiologically possible.

Rectal temperatures

Although the rectal temperature seemed to increase as the THI increased, the RT of Sahiwal, HF and crossbreds were not different. This may due to the influence of the interaction effect between breed and time (Table 2). However, taking into consideration the changing in RT of 87.5% HF and 100% HF, particularly at THI above 90, the RT was increased significantly (Figure 1c). Previous studies have found that under heat stress rectal temperatures were higher in *Bos taurus* and crossbred with higher *Bos taurus* genetic fraction than *Bos indicus* (Carvalho et al., 1995; Koatdoke, 2008).

Milk yield

Milk yield were significantly difference at days from 30 to 180 at HF100%, HF87.5%, HF50% and Sahiwal (p<0.05). The early lactation were higher at crossbred 87.5% (25 kg) than HF50% (23 kg) while the peak period of lactation was higher at HF100% (35 kg) than crossbreds of HF 87.5% and HF50% (32 kg) which was higher than Sahiwal (26 kg) (p<0.05), but it was no different at crossbred (Figure 3 and Table 3). It is possible more evaporative heat loss at crossbred HF50% than HF87% to affect lactation at crossbred dairy cattle.

CONCLUSIONS

The present study showed SR, RR, RT, and ST were significantly affected by the interaction between THI and breed. Sahiwal (*Bos indicus*) and HF50% responded to the elevated temperature by sweating, whereas 87.5% and 100% HF (*Bos taurus*) employed respiration to dissipate excess body heat. THI at 76 to 80 seems to be the critical point for Sahiwal, HF, and crossbreds to determine the method by which to dissipate excess body heat. Moreover, it is possible more evaporative heat loss at crossbred HF50% than HF87% to affect lactation at crossbred dairy cattle.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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