Pulmonary and Cutaneous Evaporative Water Losses in Sahiwal and Sahiwal × Holstein Cattle During Solar Exposure

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ABSTRACT: In order to assess the effect of solar exposure on pulmonary functions and evaporative losses from skin and pulmonary surfaces, in six healthy Sahiwal (S) and six Sahiwal × Holstein (S×H) cattle were exposed to direct sun during summer. Breed differences were observed during exposure. Increase in sweating rate was higher in crossbreds (222%) than in Sahiwal (125%). Pre-exposure (ambient temperature, 32.6±0.85℃, solar radiation, 0.9 cal cm^{-2} min^{-1}) evaporative loss from skin accounted for about 90% of the losses and remaining losses were contributed by pulmonary surfaces in Sahiwal. The contribution of evaporation through skin increased to 92% (ambient temperature 39.4±0.68℃, solar radiation, 1.35 cal cm^{-2} min^{-1}). In crossbreds 80% of the evaporative losses were through skin before exposure which increased to 87% after exposure to solar radiations. Rectal temperature increase was higher in crossbreds (1.5 ℃) than in Sahiwal (0.8℃). With the increase in pulmonary evaporative losses, respiratory frequency increased to 2 fold in Sahiwal and pulmonary ventilation increased 1.6 times the resting value in Sahiwal due to solar exposure. In S×H crossbreds the respiratory frequency increased 3.5 times and pulmonary ventilation increased only to 1.8 times due to decrease in tidal volume. There was about 2 fold increase in alveolar ventilation in both the breeds, the increase in dead space ventilation was more in crossbreds than in Sahiwal. Behavioral symptoms exhibited by animals after exposure were profuse salivation, open mouth panting, tongue protrusion and general restlesseness.
(Key Words: Pulmonary Functions, Sweating Rate, Pulmonary Evaporative Loss, Solar Exposure, Sahiwal, Sahiwal×Holstein)

INTRODUCTION

Evaporation from the skin surface is the main avenue of heat dissipation in cattle exposed to hot environments (Taneja, 1959; Allen, 1962; McDowell, 1958; Kibler and Yeck, 1959), as compared to pulmonary evaporative losses which play a complementary role (McLean, 1963). In Zebu cattle, rate of sweating has been reported to be higher than Bos taurus especially at high air temperatures (Johnson, 1970, Schleger and Turner, 1965).

In a moderately hot environment, oxen increased their respiratory minute volume by increasing respiratory frequency and by altering tidal volume (Brody, 1945, Riek and Lee, 1948). These changes in pulmonary activity are associated with altered pattern of breathing and in alveolar and dead space ventilation (Hales and Findlay, 1968). The comparative information on pattern of breathing in Hereford × Shorthorn and Brahman × Shorthorn steers is however available (Schleger and Turner, 1965) in open environmental conditions but parallel information on tropically adapted Sahiwal and Sahiwal × Holstein is not available. Since most farmers are not accustomed to keeping crossbreds, they are not familiar with behavioral pulmonary alterations, it was, therefore, necessary to know the pattern of changes in pulmonary system and functions. Such comparisons are necessary to determine the criteria for selection for efficiency of heat loss. The present paper reports results obtained on the effects of solar exposure upon the sweating and pulmonary evaporation and respiratory changes in Sahiwal and S × H cattle.

MATERIALS AND METHODS

Six healthy Sahiwal (S) and six Sahiwal × Holstein (S × H) crosses, 18-24 months old respectively weighing 209±6 kg and 136 ± 4 kg were used for experiments, During the experimental period the animals were maintained on green fodder (berseem) and wheat bhusa ad lib. Water was available ad lib except during exposure

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Received June 15, 1996; Accepted October 15, 1996

to solar raditions.

Animals were observed for their rectal temperature by using clinical thermometer and respiratory frequency measured by counting flank movements. Heart rate was calculated from ECG recorded on Dynograph recorder (Upadhyay and Madan, 1985). Pulmonary ventilation and tidal volume were measured on a spirometer (Upadhyay and Madan, 1985).

Water loss from pulmonary surface was recorded by ventilated mask method using face mask and water loss from skin was calculated by using ventilated cup (McLean, 1963). Calculations were done as decribed by Esmay (1969).

Body surface area SA (M^2) was calculated from the body weight (kg) using $SA = 0.15\ W^{0.56}$ (Brody, 1945). Pulmonary dead space of individual animal was calculated from the carbon dioxide and oxygen measured in end tidal air using OM-11 oxygen and LB-2 carbon dioxide analyser (Beckman, Illinois) and alveolar ventilation and dead space ventilation were calculated from observed values using methods outlined in "Handbook of Respiration". Respiratory Quotient was calculated from the computed values of CO_2 and O_2 as per method of Yousef (1984). In order to calculate metabolic heat production, 1 lit O_2 was assumed to be equal to 20.46 KJ (McLean, 1972).

On the day of experiment, individual animal was observed for pre-exposure standing physiological functions and were exposed to direct solar radiation for four hours continuously from 10:00 a.m. and continued for 4 hours (table 1). The results were analysed statistically as per Snedecor and Cochran (1967).

Table 1. Environmental conditions during the experimental periods

Experimental variables	Exposure time to solar radiation				
	Pre-exposure	1st hr	2nd hr	3rd hr	4th hr
Dry bulb temperature (℃)	32.6±0.85	34.7±0.98	36.5±0.98	38.6±0.70	39.4±0.68
Wet bulb temperature (℃)	23.2±0.37	24.8±0.39	25.6±0.42	25.5±0.42	25.7±0.37
Environmental relative humidity (%)	55.2±1.3	52.6±1.1	49.5±1.4	46.9±1.0	39.1±1.6
Black globe temperature (℃)	46.2±1.19	49.6±0.82	51.6±0.71	51.8±0.57	52.1±0.54
Solar radiation cal cm^{-2} min^{-1}	0.9	1.2	1.35	1.40	1.35

RESULTS AND DISCUSSION

The results on respiratory frequency, heart rate, pulmonary ventilation, volume of O_2 consumed, volume of CO_2 produced, tidal volume, dead space ventilation, alveolar ventilation, respiratory quotient, metabolic heat production, evaporative losses through skin and pulmonary surfaces and rectal temperature are presented in tables 2 and 3.

Mean pre-exposure respiratory frequency and heart rate respectively were 23 ± 1 per min and 61 ± 2 bpm in Sahiwal and corresponding values in crossbreds were 36 ± 2 per min and 67 ± 2 bpm. The change in respiratory frequency after 4 hours of exposure was significantly higher in crossbreds (90 per min) than in Sahiwal (25 per min), however the rise in heart rate was similar in both Sahiwal and S×H crossbreds.

Water loss from skin was 630±73.16 gm m^{-2} hr^{-1} in Sahiwal and 379.78±71.23 gm m^{-2} hr^{-1} in S×H crossbreds before exposure. The increase in sweating rate in Sahiwal was 125% but sweating in crossbreds was less in the beginning of the experiment which increased to three times. These changes in sweating rate were found to be correlated with ambient temperature ($p < 0.01$) and rectal temperature ($p < 0.05$) in crossbreds after 4 hours of exposure. In Sahiwal, sweating water loss was positively related to rectal temperature ($p < 0.01$) after 4 hours of exposure (figure 2).

Pulmonary water loss increased after 4 hours of exposure by 50.04 gm m^{-2} hr^{-1} in Sahiwal, and 93.44 gm m^{-2} hr^{-1} in crossbreds. Mean VO_2 in Sahiwal was 0.55±0.03 L min^{-1} before exposure which increased to 1.25±0.05 L min^{-1} after 4 hours of exposure. In crossbreds, the resting VO_2 was 0.66±0.05 L min^{-1} and after 4 hours of exposure it increased to 1.55±0.08 L min^{-1} thereby indicating that the heat exposure increased the oxygen uptake of animals. Pulmonary ventilation of Sahiwal and S × H crossbreds increased by 62% and 83% respectively. The exposure of animals to solar radiations reduced tidal volume from 1.43 ± 0.10 L to 1.25 ± 0.10 L in Sahiwal. In crossbreds, tidal volume decreased from 1.21 ± 0.04 L to 0.63 ± 0.04 L. Dead space ventilation increased after 4 hours (tables 2 and 3).

Table 2. Physiological changes in Sahiwal during exposure to solar radiations

Physiological parameters	Pre-exposure	Exposure time to solar radiation			
		1st hr	2nd hr	3rd hr	4th hr
Respiratory frequency (min^{-1})	23 ± 1	35 ± 5	39 ± 5	42 ± 6	48 ± 6
Heart rate (bpm)	61 ± 2	66 ± 2	69 ± 2	72 ± 2	79 ± 3
Pulmonary ventilation (L min^{-1})	32.98 ± 1.37	37.26 ± 1.08	43.33 ± 1.80	47.98 ± 1.56	53.53 ± 1.63
Volume of oxygen consumed (L min^{-1})	0.55 ± 0.03	0.73 ± 0.03	0.90 ± 0.05	1.04 ± 0.04	1.25 ± 0.05
Volume of carbon dioxide produced (L min^{-1})	0.46 ± 0.03	0.61 ± 0.02	0.74 ± 0.04	0.86 ± 0.04	1.04 ± 0.04
Tidal volume (L)	1.43 ± 0.10	1.21 ± 0.12	1.26 ± 0.13	1.30 ± 0.12	1.25 ± 1.10
Dead space ventilation (L min^{-1})	16.79 ± 1.18	17.04 ± 1.24	18.96 ± 1.25	18.55 ± 1.45	20.65 ± 1.33
Alveolar ventilation (L min^{-1})	17.22 ± 1.07	21.32 ± 1.24	25.48 ± 1.63	30.44 ± 1.76	34.09 ± 2.35
Mean respiratory quotient	0.83	0.82	0.82	0.82	0.82
Metabolic heat Production (KJ m^{-2} hr^{-1})	677.40 ± 44.19	906.19 ± 39.40	1,104.83 ± 62.17	1,280.04 ± 58.26	1,537.84 ± 70.48
Evaporative loss through skin (gm m^{-2} hr^{-1})	630.04 ± 73.16	999.13 ± 103.66	1,160.58 ± 105.26	1,137.97 ± 139.09	1,419.68 ± 131.73
Evaporative loss through pulmonary surface (gm m^{-2} hr^{-1})	77.94 ± 6.97	94.98 ± 5.80	102.86 ± 7.79	119.33 ± 8.81	127.98 ± 7.96
Rectal temperature (℃)	38.9 ± 0.1	39.2 ± 0.05	39.4 ± 0.06	39.5 ± 0.05	39.7 ± 0.08
Skin temperature (℃)	38.1 ± 0.04	38.9 ± 0.05	40.0 ± 0.05	41.4 ± 0.06	42.7 ± 0.07

Mean ± SE based on six number of observations.

Table 3. Physiological changes in crossbreds during exposure to solar radiations

Physiological parameters	Pre-exposure	Exposure time to solar radiation			
		1st hr	2nd hr	3rd hr	4th hr
Respiratory frequency (min^{-1})	36 ± 2	71 ± 7	93 ± 8	106 ± 6	126 ± 7
Heart rate (bpm)	67 ± 2	75 ± 2	78 ± 2	82 ± 3	86 ± 3
Pulmonary ventilation (L min^{-1})	43.12 ± 2.44	50.34 ± 2.86	58.76 ± 2.97	67.70 ± 3.58	79.04 ± 2.91
Volume of oxygen consumed (L min^{-1})	0.66 ± 0.05	0.83 ± 0.05	1.00 ± 0.06	1.24 ± 0.09	1.55 ± 0.08
Volume of carbon dioxide produced (L min^{-1})	0.55 ± 0.04	0.69 ± 0.05	0.85 ± 0.05	1.04 ± 0.07	1.29 ± 0.07
Tidal volume (L)	1.21 ± 0.04	0.76 ± 0.05	0.67 ± 0.04	0.66 ± 0.04	0.63 ± 0.04
Dead space ventilation (L min^{-1})	23.07 ± 1.94	25.84 ± 1.92	28.27 ± 1.93	31.89 ± 2.20	39.96 ± 2.51
Alveolar ventilation (L min^{-1})	21.70 ± 1.91	26.21 ± 1.89	31.71 ± 2.09	38.28 ± 3.16	44.68 ± 2.94
Mean respiratory quotient	0.83	0.83	0.85	0.83	0.83
Metabolic heat Production (KJ m^{-2} hr^{-1})	816.90 ± 67.06	1,018.90 ± 71.69	1,233.17 ± 79.16	1,531.14 ± 114.79	1,880.81 ± 96.51
Evaporative loss through skin (gm m^{-2} hr^{-1})	379.78 ± 71.23	693.40 ± 151.88	816.47 ± 254.81	979.38 ± 185.30	1,225.38 ± 286.08
Evaporative loss through pulmonary surface (gm m^{-2} hr^{-1})	92.24 ± 9.61	118.51 ± 9.70	132.4 ± 9.91	144.85 ± 13.40	185.68 ± 11.06
Rectal temperature (℃)	38.6 ± 0.1	39.5 ± 0.1	39.6 ± 0.09	39.8 ± 0.1	40.1 ± 0.12

Mean ± SE based on six number of observations.

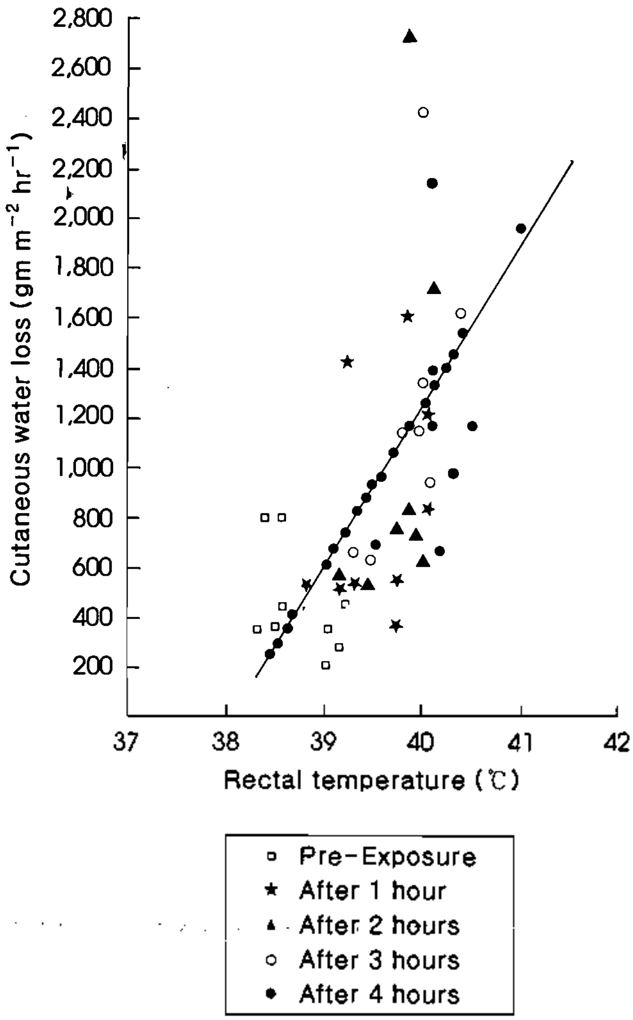

Figure 1. Relationship between rectal temperature (℃) and cutaneous water loss (gm m^{-2} hr^{-1}) pre-exposure and after 4 hours of exposure to solar radiations in crossbreds.

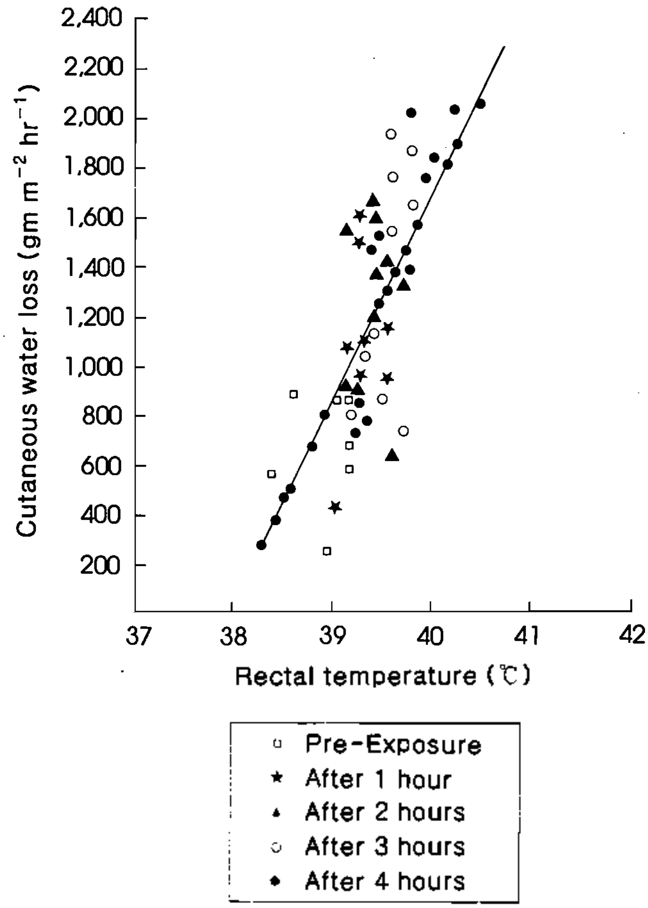

Figure 2. Relationship between rectal temperature (℃) and cutaneous water loss (gm m^{-2} hr^{-1}) pre-exposure and after 4 hours of exposure to solar radiations in Sahiwal.

The respiratory vaporization accounts for 5% of the total heat dissipation at 25℃ to 17% 40℃ in beef cattle. (Hafez and Dyer, 1969). In our experiments, we observed that respiratory vaporization accounts for 10% of the total evaporative losses in Sahiwal and 20% of total evaporative losses in crossbreds before exposure of the animals to heat. At the end of 4 hours solar exposure the pulmonary water loss increased by 1.6 times the pre-exposure value of 77.94 ± 6.97 gm m^{-2} hr^{-1} in Sahiwal and in S × H crossbreds the corresponding increase was two folds of initial pulmonary evaporative losses of 92.24 ± 9.61 gm m^{-2} hr^{-1} (table 2 and 3).

The partition of the increased pulmonary ventilation (V_E) into alveolar(V_A) and dead space ventilation(V_D) was observed to be almost similar in Sahiwal and S × H crossbreds. Hales and Webster (1967) reported in sheep that until V_E reached a level around 4 times the initial value, the increase in V_E was restricted almost entirely to the respiratory dead space. At respiratory minute volumes greater than about 4 times the initial level, alveolar ventilation increased markedly, i.e. gas exchange portions of the lungs were overventilated at this time. In our experiments, pulmonary ventilation increased 1.6-fold in Sahiwal and 1.8-fold in crossbreds. Dead space ventilation increased 1.7-fold in crossbreds while the increase in V_A was 2.0-fold. Respiratory frequency increased to 3.5-fold and tidal volume decreased about 47%, while in Sahiwal, respiratory frequency increased by 2-fold and tidal volume decreased by 12% and dead space ventilation doubled (tables 2 and 3). The alveolar ventilation increased about 2-fold in both the breeds, however, the increase in dead space ventilation was more in crossbreds than in Sahiwal. This may be due to greater increase in respiratory frequency over their initial higher resting value in crossbreds as compared to the low resting respiratory frequency and O_2 consumption in Sahiwal. It is probable that had the pulmonary ventilation increased further the alveolar ventilation would have increased more and dead space ventilation decreased.

After an initial rise of rectal and skin temperatures during the first 2 hours of exposure, then these temperatures increased marginally due to a decrease in thermal gradient between skin surface and ambient temperature. Relationship between skin temperature and sweating water loss has been shown in figure 3. Rectal temperature increased with increase in ambient temperature and the increase was more in crossbreds than in Sahiwal.

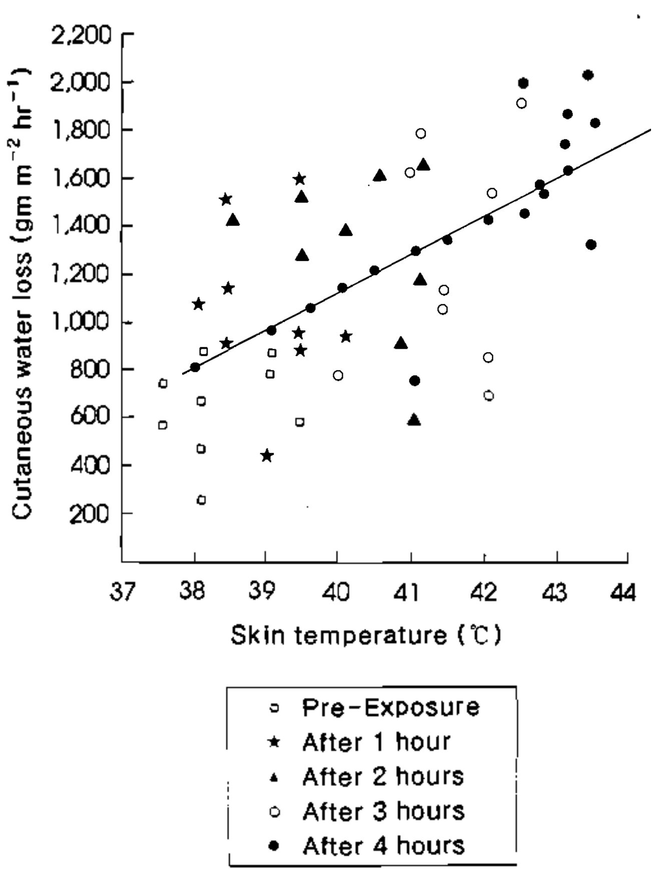

Figure 3. Relationship between skin temperature (℃) and cutaneous water loss (gm m^{-2} hr^{-1}) pre-exposure and after 4 hours of exposure to solar radiations in Sahiwal.

The sweating rates in Sahiwal were higher than in crossbreds as they were of greater body weight and relatively older. The crossbreds were of less age and body weight and depended on pulmonary evaporative losses for greater heat dissipation than Sahiwal. The increase in sweating rate due to exposure to heat for 4 hours was more in crossbreds (222%) than in Sahiwal (125%). At pre-exposure level skin evaporative loss contributed to 90% and remaining was contributed by pulmonary system in Sahiwal. The percent of evaporation through skin increased only by 2-3% after 4 hours of exposure. In crossbreds, 80% of the evaporative loss was through sweating before exposure which increased to 87% after 4 hours of solar exposure. Behavioural symptoms exhibited by animals after exposure were profuse salivation, open mouth panting, tongue protrusion and general restlessness. The ability of Sahiwal to withstand heat without any appreciable change in vaporization from skin surface reflects on their ability to maintain thermal balance and homestasis during heat exposure. Such ability of Sahiwal has enabled them to perform at an optimum level during summer and in their natural habitat of arid region.

Schleger and Turner (1965) reported lower sweating rates in Zebu crossbreds (Brahman × Shorthorn) than British Cattle (Hereford × Shorthorn) under mild hot conditons, but higher rates at higher level of heat stress. In our experiments, pre-exposure value of skin water loss was 630.04 ± 73.16 gm m^{-2} hr^{-1} in Sahiwal and 379.78 ± 71.23 gm^{-2} hr^{-1} in crossbreds. Studies of Kibler and Yeck (1959) have reported that less heat-tolerant breeds drew on evaporative cooling reserves at moderately low temperatures and were less able to increase vaporization rates at higher temperatures. Joshi et al. (1968) concluded from their studies that breeds native to India have a capability for somewhat higher sweating rates than do Zebu breeds outside India, their crosses with European breeds (Allen, 1962, McDowell et al., 1961) and pure European breeds (Allen, 1962, McDowell et al., 1961, Schleger and Turner, 1965).

Our observations indicated that sweating rates were higher in Sahiwal than S × H crossbreds when the dry bulb temperature ranged from 32.6 ± 0.85℃ to 39.4 ± 0.68℃ in summer. Data of Kibler and Yeck (1959) showed that skin vaporization rates as percentages of total vaporization were 62 and 70 in Shorthorns at 10℃ and 27℃ respectively, but 73 and 82 in Brahmans under similar conditions. Results of our findings indicated that the percentage of skin vaporization at 32℃ was 90% and 80% in Sahiwal and crossbreds respectively and at 39.4℃ the corresponding values were 92% and 87%, Thereby indicating that the capability of increasing water loss from the skin in crossbreds was not to the same extent as in Sahiwal. The higher vaporization through skin observed in present experiments was attributed to high ambient temperature and direct solar radiation exposure.

CONCLUSIONS

The solar exposure of Sahiwal and S × H crossbreds cattle revealed that Sahiwal had higher cutaneous evaporative water loss than S×H crossbred primarily due to adaptation to heat in Sahiwal. The crossbreds employed respiratory evaporative cooling and increase in respiratory frequency was much more than Sahiwal cattle. This further indicates that Sahiwal are more heat tolerant than crossbreds. The animals exhibited behavioural symptoms during exposure and profuse salivation, open mouth panting, tongue protrusion and general restlessness were more prominent in crossbreds. In order to reduce stress during summer crossbred animals require proper shelter but Sahiwal may remain near normal under solar exposure. The ability of Sahiwal to increase evaporative cooling at higher temperatures without increasing their respiratory frequency much is an important factor in establishing the heat tolerant superiority of the Sahiwal compared with the heat tolerance of crossbreds.

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