



Assessment of physiological responses and milk production in Jersey crossbred cows at different stratum of THI inside the cow barn

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ABSTRACT

Environmental heat stress is one of the restrictive factors for optimum production of dairy cows. Present study was conducted to assess alteration in cardinal physiological responses, heat tolerance indices and milk yield in Jersey crossbred cows at three levels of thermal humidity index (THI), viz. THI-1 (<72), THI-2 (72-80) and THI-3 (>80). THI levels significantly influenced rectal temperature (RT) and respiration rate (RR), but not the pulse rate. With increase in THI level 1 to 3, the RT and RR increased significantly by 0.75°F and 10.70 counts/min during morning and 0.92°F and 12.5 counts/min during afternoon, respectively. The respective enhancement between THI-2 to THI-3 was 0.48°F and 7.06/min in morning and 0.58°F and 7.45/min in afternoon. Among the cardinal physiological responses, breathing rate was the most diurnal variable parameter and it increased by 22-29% from 8:00 AM to 2:00 PM with enhancement of stress levels from THI-1 to THI-3. Measures of heat tolerance indices revealed that cows were comfortable at THI-1 and discomfort levels were prominent at THI > 80. Low yielders (<10 kg/day) resisted natural heat stress by oriented decline in daily milk yield (DMY) and sustained DMY even at THI >80. In case of high yielders (>10 kg/day) increase in THI level 1 to 2, DMY did not drop significantly; in contrast, with increase of THI-2 to THI-3, the DMY declined. It was concluded that enhanced breathing rate was the most prominent bio-indicator of natural heat stress in Jersey crossbred cows and at THI>80 production decline due to natural heat stress was non-significant in low yielders, whereas highly significant in high yielders (more than 21%). It was recommended that at THI >80, inside of cow shed needs immediate amelioration measures to diminish production losses and high yielders (>10 kg/day) warrant more attention than low yielders during heat stress.

Keywords: Jersey Crossbred cow, Milk yield, Natural heat stress, Physiological response, THI

Combined heat and humidity stress is one of the important natural characteristic features of tropical climatic conditions. It influences animals' growth, production, reproduction, health, immunity and survivability. Thermal humidity index (THI) is one of the important measures to assess stressful environmental condition. No widely accepted THI threshold for decrease in milk production is available for many breeds of dairy cows, except Holstein Friesian that is accepted to be THI 72 (York *et al.* 2017). In general, THI above 72 is considered as stressful for dairy cows (Armstrong 1994). Levels of sensitivity to temperature, relative humidity and THI varies with animal species, breeds within a species and individuals within a breed, depending upon its physiological status like growth, pregnancy, reproduction, levels of production, etc. (Colditz and Kellaway 1972, Spiers *et al.* 1994, Vale 2007, Collier *et al.* 2008, Singh and Upadhyay 2009, Misra and Mandal 2010, Singh *et al.* 2019, Mandal *et al.* 2021a,b). It also depends upon several other management factors

such as type of animal house, rearing system, feeding strategies, thermal amelioration measures adopted in the farm, geographical location of the farms, etc. (Armstrong 1994, Mandal *et al.* 2018, Mandal *et al.* 2021b, Sahu *et al.* 2019, Kumar *et al.* 2020). Alterations of cardinal physiological responses (body temperature, respiration rate and pulse rate) are the first easily observable signs under heat and humidity stress, most commonly called as heat stress. In order to maintain homeostasis, animals try to cope up the situation by behavioural and physiological changes. Estimation of these changes are necessary to know the animals' reactions and responses to stressors, capability of adjustment, occurrence of production losses and judging facilitation required for stress amelioration, if any. In exotic dairy cows, milk production started to decline THI beyond 72 in different climatic conditions (Armstrong 1994, Bernabucci *et al.* 2010), whereas, in Mediterranean climatic conditions drop in milk production was reported to occur at THI> 69 (Bouraoui *et al.* 2002). In crossbred cows the scenario might be different under tropical climatic conditions; crossbred cows are being maintained over the generations and expected to have build-up adaptive capacity under local climatic conditions.

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Therefore, assessment of changes in cardinal physiological responses in different strata of natural heat stress is very important, because these animal based indicators help devising improved management practices for higher milk production and addressing animal welfare and ethical issues under heat stress. In view of the above, present study was conducted to evaluate changes in cardinal physiological responses of Jersey crossbred cows at different levels of THI and to assess the impact of THI on milk production to frame out suitable management strategies under natural heat stress conditions.

MATERIALS AND METHODS

Animals and general management of the herd: The study was conducted on Jersey crossbred cows (N=53). The crossbred cows had Red Sindhi and Tharparkar as native indigenous base (*Bos indicus*) and Jersey (50-62.5%) as exotic (*Bos taurus*) inheritance. Study location was Eastern Regional Station, ICAR-National Dairy Research Institute, Kalyani, West Bengal. Cows were kept in loose housing system with concrete floor open paddock and asbestos sheet roofed covered area. Except milking and treatment, animals were left loose within a pen, in a group of 10-12 cows per pen. All general management and feeding practices were similar to all the animals. Cows were provided *ad lib.* seasonal green fodder, viz. Barseem, Oats, Mustard in *Rabi* season (November-March), and Maize, Cowpea, Jowar and Hybrid Napier Grass in *Kharif* season (April-October). Paddy straw was given as dry fodder and concentrate ration was given to cows as per standard routine practice of the farm. Cows had access to *ad lib.* drinking water for 24 h.

Cows were milked by machine milking twice daily (6:00-8:00 AM and 2:30-4:30 PM). Daily morning and afternoon milk yield (kg) of each cow was recorded using a digital balance. Regular daily recording of meteorological parameters of the cow shed was done for one year (2017-2018) as per standard guidelines (IMD 1970). Temperature humidity index (THI) of cow shed was calculated as suggested by Mader *et al.* (2006) using the mathematical expression:

$$\text{THI} = (0.8 \times T^{\circ}\text{C}) + [(\text{RH}/100) \times (T^{\circ}\text{C} - 14.4)] + 46.4$$

where T, temperature and RH, relative humidity (Buffington *et al.* 1981).

Recording of parameters and estimation of heat-tolerance indices: Rectal temperature ($^{\circ}\text{F}$) of cows was recorded using a clinical mercury thermometer. Respiration rates (breath/minute) were measured by observing flank and costal movements of the cow from a distance of 8-10 feet, without disturbing the animal. Pulse rate (beats/min) of cows was recorded by feeling the coccygeal artery. The sequence of recording was first respiration, followed by pulse and then rectal temperature, to minimize disturbance to cows' at lowest possible level. Physiological parameters were recorded between 8.00 to 9.00 AM and 2.00 to 3.00 PM at fortnight intervals for a period of one year. Thermo-adaptability of cows was estimated using

three indices, viz. Iberia heat tolerance (IHTC) coefficient (Rhoad 1944), Benezara's coefficient of adaptability (BCA; Benezara 1954) and Dairy Search Index (DSI; Bonsma 1949). In Iberia coefficient, an IHT value of 100 indicates the measures of perfect adaptability; decrease in value from 100 indicates beginning of discomfort to cows. In BCA and DSI, an increase in co-efficient values (BCA >2 and DSI >1) indicated decrease in heat tolerance capability (i.e. more discomfort) in cows.

Statistical analysis: The year was divided into three seasons, viz. summer (March-June), rainy (July-October) and winter (November-February). Based on THI, days were categorized into three levels of environment stress, viz. comfortable or no stress: THI-1 (<72), moderate stress: THI-2 (72-80) and high stress: THI-3 (>80). For analysis of daily milk yield (DMY) data, cows (N=40) were divided into two categories, viz. low yielders having average DMY <10 kg/day (N=26, mean age 62.59±0.40 months, range 33-165 m; average parity 2.67, range 1-9) and high yielders having DMY >10 kg/day (N=14, mean age 70.39±0.62 months, range 30-128 m; average parity 2.95, range 1-6). Milk yield records exceeding 300 days of lactation (longer lactation length) were excluded from statistical analysis. Data on meteorological parameters, thermo-adaptability coefficients and physiological indices were subjected to statistical analysis by one way ANOVA and descriptive statistics. Data on milk yield was analyzed by GLM univariate analysis of variance using the following model:

$$Y_{ijkl} = \mu + T_i + G_j + P_k + (TG)_{ij} + e_{ijkl}$$

Where, μ , Overall mean; T_i , Effect of i^{th} THI level ($i=1, 2, 3$); G_j , Effect of j^{th} cow category ($j=1, 2$); P_k , Effect of k^{th} parity ($k=1, \dots, 4$); $(TG)_{ij}$, Interaction between i^{th} THI level and j^{th} cow category; e_{ijkl} , Random error associated with Y_{ijkl} which is assumed to be normally and independently distributed with mean zero and constant variance, i.e. $\text{NID} \sim (0, \sigma^2_e)$.

Means having significant differences were subjected to post-hoc comparisons (Scheffe's Test) and considered as significantly different when $P < 0.05$. All statistical analyses were performed using SPSS 16.0 software package (SPSS 2007).

RESULTS AND DISCUSSION

The micro-environmental parameters, viz. morning (8:30 AM) and afternoon (2:30 PM) air temperature, relative humidity, thermal humidity index (THI), daily maximum and minimum temperature inside the cow shed varied significantly ($P < 0.01$) among seasons of the year (Table 1). Based on THI, forenoons of winter were comfortable (THI <72), afternoons were mild stressful (THI, 75.57±0.57) and overall basis micro-environment of cow shed during winter season was comfortable for dairy cows. Both morning and afternoon THI of cow shed during summer and rainy seasons were highly stressful for animals (Table 1). Analysis of daily THI inside the cow

Table 1. Seasonal variations in micro-environment variables (mean $\pm$ SE) inside the cow shed

	Seasons			Pooled	Significance
	Summer	Rainy	Winter		
Morning Temperature ($^{\circ}$ C)	32.13 ^a $\pm$ 0.22	31.77 ^a $\pm$ 0.18	22.34 ^b $\pm$ 0.35	28.87 $\pm$ 0.27	**
Morning Relative Humidity (%)	64.07 ^a $\pm$ 0.32	66.78 ^a $\pm$ 0.49	66.53 ^b $\pm$ 0.50	65.82 $\pm$ 0.26	**
Morning THI	83.45 ^a $\pm$ 0.31	83.36 ^a $\pm$ 0.23	69.49 ^b $\pm$ 0.50	78.95 $\pm$ 0.39	**
Afternoon Temperature ($^{\circ}$ C)	35.67 ^a $\pm$ 0.27	33.41 ^b $\pm$ 0.22	26.90 ^c $\pm$ 0.39	32.06 $\pm$ 0.26	**
Afternoon Relative Humidity (%)	62.27 ^a $\pm$ 0.32	68.72 ^b $\pm$ 0.52	60.93 ^c $\pm$ 0.46	64.13 $\pm$ 0.31	**
Afternoon THI	88.17 ^a $\pm$ 0.38	86.11 ^b $\pm$ 0.28	75.57 ^c $\pm$ 0.57	83.41 $\pm$ 0.37	**
Maximum Temperature ($^{\circ}$ C)	36.67 ^a $\pm$ 0.27	34.37 ^b $\pm$ 0.22	27.90 ^c $\pm$ 0.39	33.05 $\pm$ 0.25	**
Minimum Temperature ($^{\circ}$ C)	27.05 ^a $\pm$ 0.21	26.89 ^a $\pm$ 0.18	17.40 ^b $\pm$ 0.35	23.91 $\pm$ 0.27	**
Average THI of the day	85.81 ^a $\pm$ 0.28	84.74 ^b $\pm$ 0.23	72.53 ^c $\pm$ 0.51	81.18 $\pm$ 0.37	**

^{a,b,c} Values bearing different superscripts within the row on the respective mean values differ with each other (** $P < 0.01$).

shed indicated that only 15% days in a year fall under no stress category (THI < 72), 16% moderately stressful and 69% days were highly stressful. Mornings' thermal environment inside cow-shed was normally expected to be comfortable; however, in the present study location 59% mornings of the year were highly stressful (THI > 80). Month-wise distribution of THI (Fig. 1) inside the cow shed revealed that mornings and afternoons of December-January and mornings of November had comfortable THI, while rest of the months fell into moderate to high stress categories for dairy cows.

THI levels significantly ($P < 0.01$) affected the cardinal physiological response of Jersey crossbred cows (Table 2). Rectal temperature (RT, $^{\circ}$ F) and respiration rate (RR, counts/min) of cows differed significantly ($P < 0.01$) among three THI levels both during morning and afternoon,

being highest in THI-3, followed by THI-2 and lowest in THI-1. Both morning and afternoon pulse rate (PR, beats/min) did not differ significantly ($P > 0.05$) between THI levels. The magnitude of increase in RT and RR from THI-1 to THI-3 was 0.75 $^{\circ}$ F and 10.70/min in morning and 0.92 $^{\circ}$ F and 12.5/min in afternoon, respectively. The respective enhancement between THI-2 to THI-3 was 0.48 $^{\circ}$ F and 7.06/min in morning and 0.58 $^{\circ}$ F and 7.45/min in afternoon; between THI-1 and 2 it was 0.27 $^{\circ}$ F and 3.64/min in morning and 0.34 $^{\circ}$ F and 5.05/min in afternoon. In contrast to present observations, higher enhancement in physiological parameters were reported in Karan Fries crossbred cows and indigenous Tharparkar cows when stress was induced experimentally by subjecting cows into controlled climatic chamber continuously for 3 h at THI 72.2, 85.3 and 91, respectively (Singh *et al.* 2019). In the present investigation, the diurnal variations in RT, RR and PR (Fig. 2) indicated that RR was the most variable parameter and it increased by 22-29% from 8:00 AM to

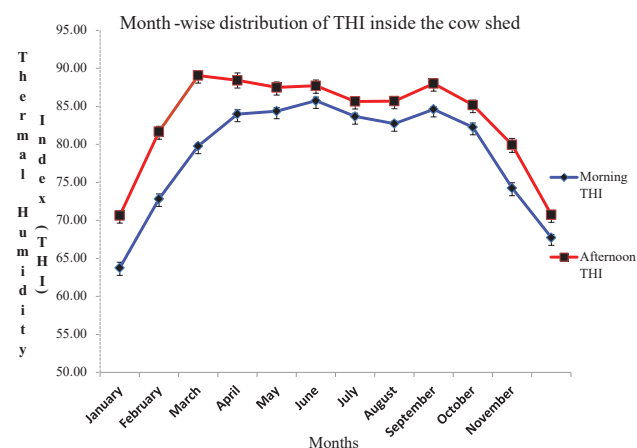


Fig. 1. THI inside the cow shed in different months of the year.

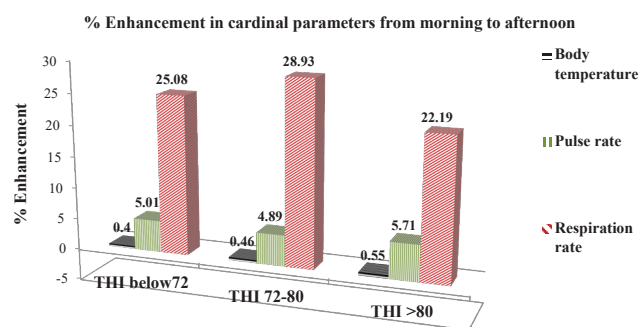


Fig. 2. Enhancement (%) in cardinal physiological parameters between 8:00 AM to 2:00 PM.

Table 2. Cardinal physiological parameters of Jersey crossbred cows under different THI levels

Particular	THI-1	THI-2	THI-3	Pooled	Significance
Morning Rectal Temperature ($^{\circ}$ F)	100.65 $\pm$ 0.04	100.92 $\pm$ 0.06	101.40 $\pm$ 0.03	101.19 $\pm$ 0.02	**
Morning Pulse Rate (beats/minute)	69.96 $\pm$ 0.46	69.67 $\pm$ 0.5	69.18 $\pm$ 0.22	69.39 $\pm$ 0.18	NS
Morning Respiration Rate (breath/minute)	13.39 $\pm$ 0.23	17.03 $\pm$ 0.39	24.09 $\pm$ 0.22	21.13 $\pm$ 0.22	**
Afternoon Rectal Temperature ($^{\circ}$ F)	101.04 $\pm$ 0.04	101.38 $\pm$ 0.06	101.96 $\pm$ 0.03	101.71 $\pm$ 0.03	**
Afternoon Pulse Rate (beats/minute)	73.37 $\pm$ 0.45	72.98 $\pm$ 0.47	73.04 $\pm$ 0.22	73.09 $\pm$ 0.18	NS
Afternoon Respiration Rate (breath/minute)	16.51 $\pm$ 0.25	21.56 $\pm$ 0.48	29.01 $\pm$ 0.25	25.68 $\pm$ 0.25	**

^{a,b,c} Values bearing different superscripts within the row on the respective mean values differ with each other (** $P < 0.01$); NS ($P > 0.05$).

Table 3. Cow-comfort indices in different THI levels

	THI-1	THI-2	THI-3	Pooled	Significance
Iberia Heat Tolerance coefficient (IHTC)	101.55 ^a ±0.40	98.50 ^b ±0.59	93.21 ^c ±0.26	95.48±0.24	**
Benezara's Coefficient of adaptability (BCA)	1.65±0.01	1.84 ^b ±0.02	2.16 ^c ±0.01	2.02±0.01	**
Dairy Search Index (DSI)	0.92 ^a ±0.00	0.96 ^b ±0.00	1.03 ^c ±0.00	1.00±0.00	**

^{a,b,c}Values bearing different superscripts within the row on the respective mean values differ with each other (**P<0.01).

2:00 PM at different THI levels. The RT and PR showed less diurnal variations. Similar to present findings, in Frieswal cattle diurnal variation in RT, RR and PR had been reported and those variations formed the basis of testing thermo-adaptability of Frieswal crossbred bulls (Mandal and Tyagi 2008). In percentage terms RT might show least variations; however, increase in RT by a minute degree provided an indication for retention of heat load inside the body. Thus, elevation in RT displayed inadequate heat dissipation by evaporative cooling (respiration, sweating, enhanced peripheral blood flow, etc.) and prognosticated that normal thermo-regulation had been compromised somewhere in the animal system due to heat stress.

Table 3 depicts the cow comfort indices in different THI levels. Deviations in physiological responses to stressors depend upon degree of stress and individual capacity of animal to cope up the adverse situation. These capacity comparisons between individuals or group of animals depict heat/thermo-tolerant ability and it was estimated by various heat tolerance indices, viz. IHTC, BCA and DSI (Mandal and Tyagi 2008, Mandal *et al.* 2021b). Stressors imposed on animal system initiate physiological changes and are detectable by alterations in RT, RR and PR, which are valid index of social stress/discomfort in large animals (Guyton and Hall 2006). Thus, estimation of heat tolerance indices on a group of cows directly indicates the levels of cow-comfort in the existing environment and management. In the present study discomfort levels of cows increased significantly (P<0.01) as the THI levels increased from <72 to above 80 (Table 3). The IHTC value less than 100 indicates the initiation of stress. In the present study, with increase in THI level IHTC decreased significantly (P<0.01) and the

magnitude of decline was more between THI-2 to THI-3, which indicated higher discomfort to cows after THI 80. In case of BCA and DSI, higher value of coefficient indicates higher the level of discomfort to animals. The BCA and DSI increased significantly (P<0.01) with increase in THI levels (Table 3). All the three measures of heat tolerance/cow-comfort indices showed more discomfort of cows with increased THI and it became very prominent when THI increased above 80 (THI-3).

The comfort levels of cows also showed significant (P<0.01) monthly variations in the present study (Table 4) and this might be due to cumulative impact of daily THI. The obtained results indicated that when THI levels inside the cow shed exceeded 80 (THI-3), ambient stress amelioration measures need to be initiated to ensure cow-comfort and prevention of drop in production due to heat stress. Month-wise variation in cow comfort level (Fig. 3) in the existing management system indicated that cows were comfortable (BCA less ≤2) during November to February and also in the month of July when the BCA index was close to 2. Hence, present findings indicated that thermal stress amelioration for Jersey crossbred cows was warranted in March-June and August-September in tropical climatic conditions of the study area, in broader sense lower Gangetic plains of West Bengal and areas having similar climatic conditions. In these months THI levels of cow shed during afternoon were mostly above 80 (Fig 1), which indicated the necessity of stress amelioration during afternoon.

Table 5 depicts the effect of THI levels, parity, cow category and interaction of THI × cow category on milk yield of Jersey crossbred cows. All the factors significantly

Table 4. Month-wise distribution of comfort indices of Jersey crossbred cows

Month	IHTC	BCA	DSI	Significance
January	102.22 ^f ± 0.61	1.63 ^a ± 0.01	0.92 ^a ± 0.00	**
February	96.61 ^c ± 0.69	1.86 ^b ± 0.02	0.97 ^b ± 0.00	**
March	95.07 ^c ± 0.96	2.15 ^{de} ± 0.04	1.03 ^d ± 0.01	**
April	91.71 ^{bc} ± 0.73	2.19 ^{de} ± 0.02	1.04 ^d ± 0.01	**
May	92.83 ^{cd} ± 0.58	2.17 ^{de} ± 0.02	1.04 ^{de} ± 0.01	**
June	88.08 ^a ± 0.89	2.22 ^{ef} ± 0.03	1.05 ^{de} ± 0.01	**
July	95.45 ^c ± 0.43	2.04 ^c ± 0.02	1.00 ^c ± 0.00	**
August	94.40 ^{de} ± 0.77	2.28 ^{fg} ± 0.02	1.04 ^{de} ± 0.01	**
September	90.62 ^b ± 0.73	2.34 ^g ± 0.03	1.06 ^e ± 0.01	**
October	94.98 ^c ± 0.85	2.13 ^d ± 0.03	1.01 ^c ± 0.01	**
November	101.33 ^f ± 0.5	1.81 ^b ± 0.02	0.95 ^b ± 0.01	**
December	101.48 ^f ± 0.55	1.67 ^a ± 0.01	0.93 ^a ± 0.00	**
Overall	95.48 ± 0.24	2.02 ± 0.01	1.00 ± 0.00	**

^{a,b,c,d,e,f,g}Values bearing different superscripts within the row on the respective mean values differ with each other (**P<0.01).

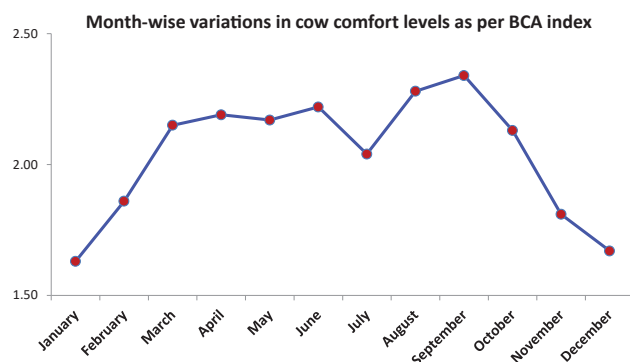


Fig. 3. Depiction of cow-comfort levels in different months of a year.

affected morning, afternoon and total daily milk yield. THI significantly ($P < 0.01$) affected daily milk yield (kg/day/cow) of high yielding Jersey crossbred cows (Table 5), but not the low yielders. The variations in milk yield of low producer Jersey crossbred cows in different THI levels were non-significant ($P > 0.05$). In high producer cows daily morning, evening and total milk yields were significantly ($P < 0.01$) lower in THI-3 as compared to THI-1 and THI-2. Between THI-1 and THI-2, the DMY did not differ significantly ($P > 0.05$) in high yielding cows. Obtained results indicated that impact of heat stress on milk production was very prominent in high producers, whereas, in low producers daily milk yield was least affected even at $\text{THI} > 80$. Therefore, the general concept on the requirement of heat stress amelioration at THI exceeding 72 might

not hold applicable for Jersey crossbred cows. Animal's discomfort/ beginning of stress might occur even at lesser THI, depending upon the breed, however animals' adaptive capacity play roles to maintain production. In an earlier study (Mandal *et al.* 2021b) it was reported that increase in respiration rate $> 35\%$ and rectal temperature of $+ 0.5^\circ\text{F}$ than normal could be considered as initiation of stress signs in Jersey crossbred cows and need heat stress ameliorative interventions.

In high producers, increase in stress levels from THI-2 (range 72-80; mean 76.14) to THI-3 (range 80-93; mean 85.37) the DMY significantly reduced from 12.93 ± 0.12 to 10.19 ± 0.07 kg, i.e. increment of 9 unit THI from level 2 to 3, the milk yield was decreased by 2.74 kg/day/cow. In a simplified extrapolation, this could very grossly be estimated that with per unit increase in THI from 76 to 85, milk yield of Jersey crossbred cows decreased by 304 g/day/cow. In Tharparkar and Karan Fries cows per unit increase in THI from 72.2 to 85.3 caused decrease in milk yield by 19.08 ml and 136.64 ml per day in a very short term study, when stress was induced experimentally by subjecting cows into controlled climatic chamber continuously for 3 h for 3 consecutive days (Singh *et al.* 2019). Short term stress induction might not exactly mimic the actual ambient stress in which animals are exposed during the entire seasons. In Mediterranean climatic condition, drop in milk production by each point increase in THI beyond 69 was 410 g/ cow/ day (Bouraoui *et al.* 2002). Bernabucci *et al.* (2010) reviewed the impact of

Table 5. Milk yield of high and low yielding Jersey crossbred cows in different THI levels

Particular	MMY	AMY	DMY
<i>Effect of THI levels</i>	$p < 0.001$	$p < 0.001$	$p < 0.001$
THI-1	$6.87^a \pm 0.05$	$3.33^a \pm 0.03$	$10.20^a \pm 0.07$
THI-2	$6.79^a \pm 0.05$	$3.37^a \pm 0.03$	$10.15^a \pm 0.08$
THI-3	$5.84^b \pm 0.03$	$3.01^b \pm 0.01$	$8.85^b \pm 0.04$
<i>Effect of Parity</i>	$p < 0.001$	$p < 0.001$	$p < 0.001$
1	$5.91^a \pm 0.04$	$3.01^a \pm 0.02$	$8.91^a \pm 0.06$
2	$6.83^b \pm 0.04$	$3.41^b \pm 0.02$	$10.24^b \pm 0.06$
3	$6.90^c \pm 0.04$	$3.27^c \pm 0.02$	$10.17^c \pm 0.06$
≥ 4	$6.35^d \pm 0.04$	$3.26^c \pm 0.02$	$9.60^d \pm 0.06$
<i>Cow Category</i>	$p < 0.001$	$p < 0.001$	$p < 0.001$
LY	$5.06^a \pm 0.02$	$2.46^a \pm 0.01$	$7.51^a \pm 0.04$
HY	$7.94^b \pm 0.04$	$4.02^b \pm 0.02$	$11.95^b \pm 0.07$
<i>Cow Category $\times$ THI levels</i>	MMY $p < 0.001$		AMY $p < 0.001$
	LY	HY	LY
THI-1	$5.07^a \pm 0.05$	$8.66^a \pm 0.08$	$2.40^a \pm 0.02$
THI-2	$5.12^a \pm 0.05$	$8.45^a \pm 0.09$	$4.27^a \pm 0.05$
THI-3	$4.98^b \pm 0.03$	$6.69^b \pm 0.05$	$4.29^a \pm 0.05$
			DMY $p < 0.001$
			LY
THI-1			$7.47^a \pm 0.07$
THI-2			$12.93^a \pm 0.12$
THI-3			$7.57^a \pm 0.08$
			HY
THI-1			$12.74^a \pm 0.13$
THI-2			$10.19^b \pm 0.07$
THI-3			$10.19^b \pm 0.07$

^{a,b,c,d} Column-wise means with different superscripts within the parameters differ significantly ($P < 0.001$); THI-Thermal Humidity Index; MMY-Morning Milk yield (kg)/cow; AMY-Afternoon milk yield (kg/cow); DMY-Daily Milk yield (kg/cow/day); LY-Low yielder cows ($\text{DMY} < 10$ kg/day); HY- High yielder cows ($\text{DMY} > 10$ kg/day).

heat stress on milk yield and reported that milk production declined per unit of THI beyond 72 ranging from 0.23 to 0.59 kg/day in different climatic conditions. Present study reported that Jersey crossbred cows maintained in tropical climatic conditions of lower Gangetic region of India, the drop in milk production was not significant at THI up to 80 (Table 5). These might be due to breed variations and difference in housing and feeding management of farms. In the experimental farm, cows are reared under loose housing system in 3 side open shelters with roof, which is comfortable than closed dairy barns. Crossbreds of Jersey are being reared in the farm more than 40 years through several generations and they might have adjusted to local environment over the generations. Moreover, there exists breed variation in response to heat stress, for example, Holstein Friesian (HF) cattle were more sensitive to the effects of heat or cold stress as compared to New Zealand Jersey (NZJ) cattle and crosses of HF $\times$ NZJ remained at intermediary position (Bryant *et al.* 2007). Significant differences are there in heat tolerance of *Bos indicus* and *Bos taurus* cattle. Indian native breeds, Sahiwal, Tharparker and crossbreds like Frieswal, Karan Fries, crossbred Jersey were found to have different heat stress responses in terms of rectal temperature, respiration rate, peripheral blood flow, skin temperature and production parameters under varying levels of stress conditions (Mandal and Tyagi 2008, Mandal *et al.* 2016, Sajjanar *et al.* 2015, Singh *et al.* 2019). Beyond the THI 80, high yielding Jersey crossbred cows could not maintain production performance persistently and milk yield declined by 21% in this study. In contrast, low yielding (<10 kg/cow/day) Jersey crossbred cows' maintained production under all THI levels and low producer cows were apparently more sustainable to the present production environment. However, it needs detailed economic analysis in future. The increased susceptibility of high yielding cows to heat stress was primarily due to their higher metabolic rate, more production stress, probable energy deficiency and diversion of energy from production to heat dissipation to maintain thermoregulation, which is the primary need of homeotherms (Purwanto *et al.* 1990, Renaudeau *et al.* 2010, Bernabucci *et al.* 2010). As compared to non-lactating cows, heat production from lactating cows yielding 18.5 and 31.6 kg milk/day was 27.3% and 48.5% higher, respectively and these findings indicated that high yielders had a gross difference of 21% more heat production than low yielders (Purwanto *et al.* 1990). This increased sensitivity to heat stress of high yielders might be due to production stress associated with synthesizing additional milk (Purwanto *et al.* 1990), which supports the present findings that in low producing Jersey crossbred cows the DMY did not decline even at THI >80, whereas, in high producing cows reduction was non-significant up to THI level 2 (72-80), but highly significant at THI-3 (>80).

It can be concluded that increase in cow shed THI > 72 significantly ($P < 0.01$) affected rectal temperature and respiration rate of Jersey crossbred cows, but not the

pulse rate. Among the cardinal physiological parameters breathing rate showed the most diurnal variations and it was increased by 22-29% between 8:00 AM to 2:00 PM with enhancement of stress levels THI-1 to THI-3. The changes in respiration rate, rectal temperature and discomfort of cows were more prominent at THI above 80. Low yielding cows sustained productivity at higher THI (>80); high yielders maintained productivity up to moderate THI (72-80), and thereafter (THI>80) milk yield declined significantly. It was suggested that at cow-shed THI beyond 80, heat stress amelioration measures need to be initiated for Jersey crossbred cows, at least for those yielding >10 kg milk/day.

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