Review paper

Effect of heat stress on physiological responses in dairy cattle: A systematic review

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ABSTRACT

The ever-changing climate as evidenced by the erratic weather phenomena globally and in India, poses a daunting challenge to the livestock industry. The already stretched resources of agriculture and livestock in the country is threatened due to unpredictable climate patterns, further worsening thermal stress on animals, especially dairy cows. Better understanding of effect of climate on the animals will help in better management decisions and at the same time enhancing animal welfare. With this article, we tried to review the mechanisms associated with heat stress in cows and their associated physiological response.

Key words: heat stress, dairy cows, temperature humidity index, climate change, physiological responses.

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INTRODUCTION

In the last few years, there has been growing concerns with regard to climate change. The various extreme weather events witnessed globally, substantiates the fact that climate change is well underway. Various studies have anticipated that climate change associated with heat stress is going to affect all living forms adversely. By the year 2030, the environmental temperature in India is expected to rise by 0.5°C and by the end of this century this may go up to 2-4°C with maximum increase predicted to be in the northern part of India (Shukla, 2003). Thermal stress is known to exert a profound effect on various physiological parameters and overall productivity of dairy animals hence, climate change does not bode well for the livestock sector. Increased in average environmental temperature concomitant with reduced rainfall as a consequence of climate change, jeopardizes the sustainability of the livestock production (Scholtz *et al* . 2013), especially in the tropical countries (Cardoso *et al* . 2015). India being a tropical country, high temperature associated with high humidity imposes extra heat load on dairy animals adversely impacting the productivity of animals. Hot summers and cold winters with heavy rainfall clustered over a few days that epitomizes the erratic weather phenomena in the country is stressful to the rainfed agriculture systems and Indian livestock sector. As the surface temperature in India has been recorded with increasing trend (Figure 1), it presents a formidable challenge for the animal sector. The increase in intensity and frequency of heat waves in India will put dairy animals, under substantial thermal stress.

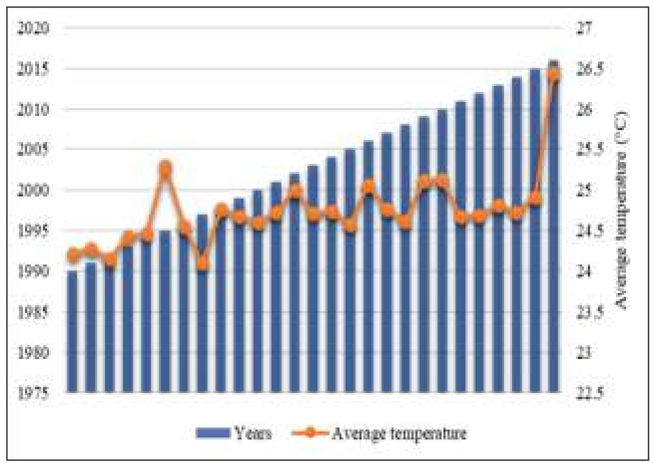

Figure 1. Trends in average temperature of India (1990-2016). Data source: Indian meteorological department (IMD), New Delhi

India has the second largest cattle inventory in the world with 12.88% of cattle (World Cattle Inventory: Ranking of Countries, USDA, 2020). Currently, 50 breeds of native cattle have been registered in India which has been categorized into milch, dual purpose and drought purpose breeds. Sahiwal, Gir, Rathi, Red Sindhi, Tharprakar are the major milch breeds of India. Kankrej, Deoni, Hariana are famous dual-purpose breeds while Ongole, Amrit Mahal, Kangayam and Nagori are well known drought breeds of India known to perform even under harsh conditions. Although, climate change will have significant impact on the Indian dairy industry, however, these Indian native cattle breeds with genetic traits conferring them with thermotolerance, should be central to breeding policies to be undertaken as the adaptational strategy (45th Dairy Industry Conference, NDDB).

General impact of heat stress on cattle breeds

The thermoneutral zone at which there is minimum physiological pressure for dairy animals is between 5-25^{0}C. Every species has a defined range of TNZ (Figure 2), that extends from the lower critical temperature (LCT) to the upper critical temperature (UCT). Dairy animals are sensitive to UCT. Even a rise of 1 ºC temperature from the UCT can lower the animal production (McManus *et al*. 2009). Adult cattle of temperate-region have a thermal comfort zone ranging from 5–25 °C with optimal productivity (Hahn *et al* .1999; West, 2003). Tropically adapted dairy animals on the other hand have better coping mechanism against thermal stress (Hahn *et al*. 1999; Indu *et al*. 2015). TNZ depends on various factors *viz*., animal species, breed, age, physiological state or adaptation, which is further influenced by other environmental conditions (Sanz, 2016).

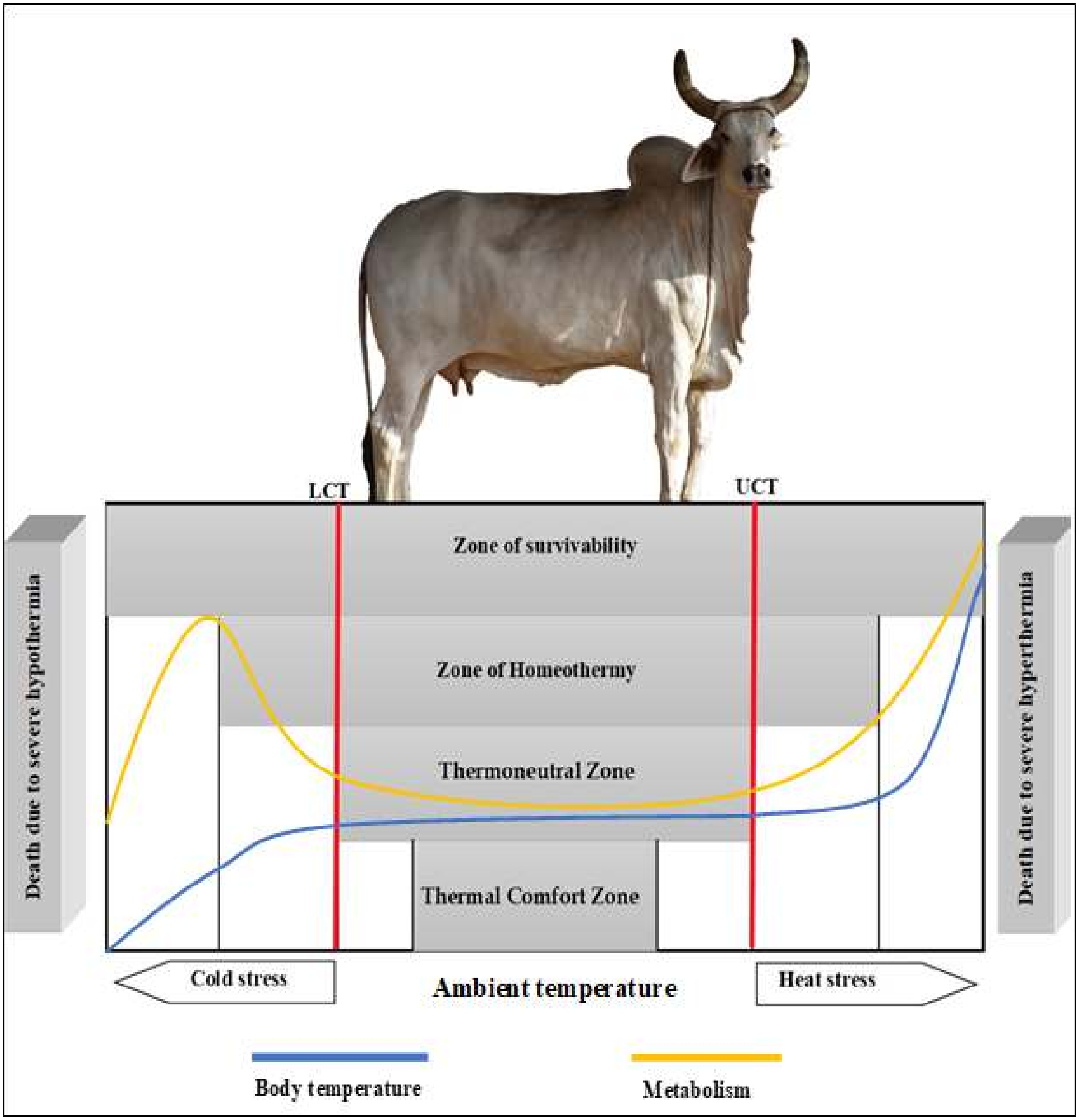

Figure 2. Lower (LCT) and Upper (UCT) critical temperature of cow and physiological response

Exposure to high ambient temperature induces the animal's adaptive mechanism to minimize the impact of excessive heat load by using different means (conduction/ convection) to dissipate the excessive heat. In all vertebrates, the ability to change blood flow to the periphery during thermal stress is a part of their first physiological feature of the thermoregulation machinery. At morphological and anatomical level, the skin color, presence of numerous sweat glands, coarse/ dense skin hairs on the body also help to regulate the heat exchange properties of an animal. The physiological mechanisms for coping with heat stress also include greater vasodilatation with increased blood flow to the skin surface, sweating and a more rapid respiratory rate. These are some of the normal thermoregulatory physiological mechanisms that animal undergoes to transfer heat from body to the surrounding environment. The thermoregulatory mechanism helps the animals to maintain the core body temperature within a narrow limit so that normal biochemical, physiological and metabolic processes can be performed.

As a basic thermoregulatory strategy, dairy animal tends to maintain the core body temperature higher than ambient temperature. This allows the heat to flow out from the core via four basic routes of heat exchange (conduction, convection, radiation and evaporation). In situations where environmental temperature exceeds body temperature, heat flow will be reversed and as a result the animal will become heat stressed and experiences higher rectal temperature and respiration rate. Other immediate responses of animals to exposure to hyperthermia are decreased nutrient and dry matter intake, reduced rate of metabolism and altered water metabolism in response.

High producing dairy animals are more impacted by heat stress due to the higher production stress, greater metabolic heat production and limited thermo-neutral zone (TNZ) compared to low yielders. When the UCT is breached, the adaptive mechanisms of animals fail to remove the excess heat generated, which then ceases to maintain homeothermy, resulting in heat stress (Berman *et al* . 2011; Bernabucci *et al* . 2014). High environmental temperatures concomitant with high relative humidity in the animals' surrounding is associated with the problem of heat stress (Hill and Wall, 2015).

Heat stress brings about numerous challenges leading to alterations of the normal physiological mechanisms and thus brings out stressful response (Collier *et al*. 2006). The conditions like sustained high temperature associated with reduced precipitation, have reasonable impact on variety of dairy parameters including fertility, milk production, feed intake, growth, conception rates and animal health. Many researchers have tried to define heat stress in their own terms. However, the consensus statement says that heat stress is the sum of external forces that modifies the body temperature of animals above that of their resting state, which in turn elicits a physiological response (West, 2003; Dikmen and Hansen 2009).

The susceptibility of heat stress in cows is influenced by its breed, age and lactation phase, level of milk production, feed and water intake levels, feed consumed, body condition score and the use of technical solutions to manipulate the animal's microclimate (Kadzere *et al* . 2002; West, 2003). Various climatic factors like ambient temperature, relative humidity, radiation and wind also influence the degree of heat stress (Samal, 2013).

Temperature humidity index as an indicator of heat stress

Researchers have used temperature humidity index (THI) as environmental parameter to evaluate environmental heat stress. This index combines relative humidity and temperature into a single value to estimate the potential environmental heat load (Polsky and von Keyserlingk, 2017). THI is an important indicator which has been efficiently utilized to assess heat stress levels and its impact on the productivity of dairy cattle (Vaidya *et al*. 2010; Gantner *et al*. 2011)**.** Most often than not, an environment is generally considered stressful for dairy animal when the THI exceeds 72.

THI above 72 may exert adverse effects on different breeds of cattle and buffaloes depending upon their adaptability to tropical climatic conditions (Jeelani *et al*. 2019). Generally, hot-humid season record higher THI score as compared to hot-dry and winter seasons (Aggarwal and Singh, 2010; Singh *et al*. 2014). Based on the earlier studies, THI value below 72 is ideal for tropical animal husbandry, THI values between 72 to 88 causes mild heat stress, while a value above 88 causes extreme heat stress in the tropically adapted cattle. While in case of temperate cattle breeds, a THI value below 68 units is considered comfortable while such animals become slightly uncomfortable at THI between 68 to 74, but at a THI above 75 units, the animals experiences great discomfort and noticeable reduction in their performances (Ravagnolo *et al* . 2000; Bouraoui *et al*. 2002; Hahn *et al*. 2003). Thus, the physiological feedback of dairy cows to the surrounding climatic environment can be evaluated by determination of THI thresholds for the performance of dairy cows which mandates an efficient measurement of heat stress conditions (Schüller and Heuwieser, 2016). In a nutshell, the calculation of critical THI thresholds helps in efficiently comparing the heat stress conditions and consequent physiological responses of dairy cows between breeds (Smith *et al*. 2013), varied housing conditions (Gorniak *et al*. 2014), heat amelioration strategies (Honig *et al*. 2012) or even at the level of individual cows (Schüller and Heuwieser, 2016).

As THI formulae deriving the environmental risk factors, only considers the factors that shape the microclimate of the animal, it unfortunately renders them imperfect. Other indicators driving cow response are not assessed *viz*, the location inside barn (Schüller and Heuwieser, 2016), wind speed, ventilation or even the role of the floor (ground) in animal cooling (Herbut *et* al. 2018). Thus, extending the scope of research to devise an index which is more precise will help in evaluating stress on animals and consequent animal management decisions.

Impact of heat stress on physiological responses

Acute stresses are often well tolerated, despite inducing transient physiological variations, mostly endocrine and metabolic. However, chronic stress conditions have welfare implications. Though less evident, chronic stress resulting in alteration of endocrine, physiological and immune functions over a period of time occurs with pre-pathological or pathological consequences (Trevisi and Bertoni, 2009**).** Lower feed intake with disturbed protein and energy metabolism, altered enzymatic reactions, mineral balance, hormones and metabolites secretion, decline in activity, high tendency of animal to seek for shade and wind with increase in respiratory rate, peripheral blood flow and sweating are evident in animals subjected to heat stress (West, 2003; Delfino *et al*. 2012; Sreedhar *et al*. 2013). Reduced milk production, growth, and reproductive rates occur as a result of heat stress, predisposing the animal to various diseases and in turn incurring economic losses (Nardone *et al*. 2010).

Heat stress exerts potential hazards and interfere with the growth and production of domestic animals. Simultaneously high environmental temperature and air humidity enhances heat stress resulting in depression of physiological and metabolic activities (Ganaie *et al*. 2013**).** Physiological, cellular and biochemical responses vary among animals when subjected to thermal stress, and the performance of animal under heat stress helps in measuring its overall ability to cope with heat (Carabaño *et al*. 2019). The negative effects of heat stress on the feed intake of animals, their growth, and the quality and production of milk, and meat puts significant financial burden on the global animal agriculture (Dunshea *et al*. 2013).

When an animal is subjected to heat stress, its physiological responses are noticed at the initial level followed by endocrinal changes (Wankar *et al*. 2017). There exists a positive relationship between THI and physiological parameters (Bhan *et al*. 2012; Kim *et al*. 2018). As animals try to cope up by varying the physiological traits like rectal temperature (RT), respiration rate (RR), pulse rate (PR)/heart rate (HR), and skin temperature (ST), the productivity gets compromised in most species as they try to maintain regular energy supply for vital physiological functions (Aleena *et al*. 2016). Amongst various physiological responses, RT and RR are the most sensitive indices of thermal stress (Verma *et al*. 2000), PR/HR has also been implicated in heat stress response and routinely used as an indicator of heat stress in animals.

An animal's answer to heat stress comprises mainly of increasing heat loss, as the information on the ST and internal temperatures is perceived by specialized nerve receptors *i.e*., the thermoreceptors located throughout the body (Curtis, 1983). Neuronal and neurohormonal systems, that includes the immune system gets activated as a consequence of heat stress. The intensity of stress response and their consequences on an organism is in turn determined by the degree of the stimulation of these systems. Hence, physiological and behavioural disturbances are mere mechanisms of animal adaptation when their homeostasis is disturbed (Adamczyk *et al*. 2015). Comparatively, tropically adapted *Bos indicus* experiences less pronounced physiological changes as compared to temperate adapted *Bos taurus* cattle when exposed to continuously high heat and humidity**.** (Beatty *et al*. 2006).

Variation in RT *i.e.,* ΔRT has been widely used to assess the heat stress response in animals (Otto *et al*. 2019), it provides insights into the thermoregulatory shift when animal is subjected to heat stress. RT indicates the thermal equilibrium of animal body, when raised, it generally points toward failed or exhausted thermoregulatory mechanisms that follows heat stress (de Andrade Ferrazza *et* al. 2017). The sensitivity of RT to harshness of thermal environment makes it a useful indicator to judge the core body temperature of an animal in response to thermal stress and as an index of discomfort (Silanikove, 2000; Omeran *et al*. 2011). The general trend in RT observed during hotter ambience is that of an increase with an increasing temperature. Although the maintenance of core body temperature is a homeostatic process on animal's part, higher environmental temperature compromises this ability. As temperature rises, the heat dissipation capacity is massively impacted, and a situation comes when even evaporative cooling fails. The exhaustion of this mechanism results in a resultant loss in heat dissipation ability, gradually rising the core body temperature, as reflected in higher RT during thermal stress. In dairy cows, there is greater metabolic heat production, this further reduces the thermoregulatory capability. The RT in animals is influenced by a number of factors, ranging from physiological state, species, level of production, feeding, seasons, time of the day, among other things (Beatty *et al*. 2006; Bhan *et al.* 2012; Sailo *et al.* 2017). To assess the significance of RT changes bound to different thermal stress thresholds, various studies have been carried out over time. Studies involving Holstein cows revealed 1°C increase in RT when cows were subjected to heat stress compared to thermoneutral environment (Amamou, *et al.* 2019) and a 1.6°C rise in RT from 38.67 ± 0.03 to 40.27 ± 0.05 when THI increased from 76.59 ± 0.06 to 89.87 ± 0.14 (de Andrade Ferrazza *et al.* 2017). Further, Perano *et al.* (2015) reported a 0.2°C increase in RT with a point change in THI from 79.0 ± 1.0 to 80.7 ± 0.9, while, Bouraoui *et al.* (2002) observed a daily increase of 0.5°C in RT when THI value increased from 68 to 78. Similar findings of increase in RT from 38.73 to 39.43 °C and 39.18 to 39.65 °C was reported by Srikandakumar and Johson, (2004) in Holstein and Jersey cows, respectively. However, in the same study the increase in RT with THI was least in American zebu cows, from 38.67 to 39.05 °C. It is a well-established that the zebu breeds due to their evolution in harsh thermal environments, have better thermotolerance. Maibam *et al.* (2019) evaluated the effect of seasons and breeds on RT and found higher RT during summer in both Tharparkar (*Bos indicus*) and Karan Fries (crossbreed) cows, however, crossbred cows had higher increase in RT from 38.13°C in winter to 39.47°C in summer, but the increase of RT in Tharparkar cows was much lower, from 37.84°C in winter to 38.88°C in summer. In another study, while evaluating the differences in physiological responses of Sahiwal cows (*Bos indicus*) and Karan Fries cows (crossbreed), Sailo *et al.* (2017) found a higher increase in RT of Friesian crossbred (from 37.49 to 39.19 °C) from winter to summer, compared to zebu cows (from 37.30 to 38.81°C), suggesting better heat tolerance in zebu breeds. It further affirms that zebu breeds have lower physiological response when they are subjected to similar thermal stressors as their taurine and crossbred counterparts. Moreover, the diurnal variations in RT in case of taurine cattle is generally found higher, due to more increase during hotter parts of the day. Espinoza *et al.* (2009) reported a diurnal difference of 1.13 ± .07 and 1.01 ± .05 in RT of Holstein and Jersey cows, while the difference was only 0.78 ± .02 in local Chinampo cows. The higher response in taurine breeds is mostly attributed to their evolution under lower temperature, as well as greater production stress. The higher RT in heat stressed animals has been attributed to disturbed homeothermy in that breaks down heat dissipation through physical and physiological processes of thermolysis (Joshi and Tripathy, 1991).

When there is excessive heat load, the thermoregulatory mechanism of an animal tries to get rid of the excess heat by making shift in physiological mechanisms. The rise in core body temperature due to excessive heat load compromises convectional or conductional heat loss from animal body, making evaporative heat loss to be only feasible outlet. As animal tries to lose heat by evaporation, the RR increases to lose more heat, making increase in RR to be one of the most visible changes in response to heat stress. If heat load increases further, animal even restores to panting, which indicates severe heat stress. RR is known to be a powerful indicator of heat stress and is significantly correlated with circulating corticoids concentration (Kumar, 2005; Sejian *et al.* 2010). RR has been evaluated as an important measure of heat stress by many researchers over the years. Scharf *et al.* (2010) and de Andrade Ferrazza *et al.* (2017) opined that continuous exposure to intense heat stress influences the thermoregulation in animals, resulting in marked increase in RR, and subsequent increase in RT. Research in taurine breeds has revealed a 2.3-fold in RR when THI increased from 54 ± 4.3 to 77 ± 2.5, with the increase in RR by 2 breaths per min for one-point increase in THI (Amamou, *et al.* 2019) and Al-Kanan (2016) observed an increase in RR concomitant with increasing THI, especially for THI > 65 when German dual purpose cows were subjected to heat stress. While an increase in THI from 68 to 78 yielded an increase of 5 inspirations per min in Holstein dairy cows reared in Mediterranean set up (Bouraoui *et al.* 2002). Gaughan *et al.* (2000) observed that RR varied from 2.8 breaths/min to 3.3 breaths/min for every 1°C increase in ambient temperature under hot ambience in taurine steers. The RR of an animal is also influenced by the species, breeds, physiological states, seasons, time of the day and degree of leanness (Gaughan *et al.* 2000; Koubkova *et al.* 2002; Sakatani *et al.* 2012; Sailo *et al.* 2017). Furthermore, Espinoza *et al.* (2009) reported a diurnal difference of 15.0 ± 1.9 and 19.6 ± 1.9 in RR of Holstein and Jersey cows, while the difference was only 5.3 ± .51 in local Chinampo cows indicating higher heat load in taurine cattle. The increase in RR of Karanfries cows from 15.77 breaths/min (winter) to 47.29 breaths/min (summer) as compared to a rise from 15.74 breaths/min (winter) to 29.81 breaths/min (summer) in a study carried out by Sailo *et al.* (2017) indicates higher heat load in crossbred cows during hotter ambience. Additionally, Beatty *et al.* (2006) carried out a study to evaluate the difference in responses to thermal stress between Bos indicus and Bos taurus cows, they revealed that even prolonged exposure to heat and humidity did not produce clinical signs of heat stress in Bos indicus animals, but the same exposure produced clinical signs of heat stress like open-mouthed panting, drooling and general dullness including neurological manifestations. A fall in RR with increasing ambient temperature may be indicative of animal's failure to cope up with the thermal stress (Gaughan *et al.* 2000). Comparatively, the magnitude of increase in RT and RR were found to be higher during summer and hot humid condition (Korde *et al.* 2007; Bhan *et al.* 2012; Singh *et al.* 2014; Chaudhary *et al.* 2015; Sailo *et al.* 2017; Lakhani *et al.* 2018**).** Across season, studies have revealed higher RT, RR, PR and ST during hot-dry and hot- humid season when compared to winter season (Sakatani *et al.* 2012, Singh *et al.* 2014, Lakhani *et al.* 2018).

The circulatory and respiratory dynamics is under the influence of period of the day, prevalent climatic conditions, season, workload, among other things (Marai *et al.* 2007). When exposed to high ambient temperature, PR usually increases and that makes PR a reliable indicator to assess heat stress in cows (Das *et al.* 2016). Increase in PR is a key indicator of metabolic shift in the animal's body to ward off the excessive heat. However, ambiguity exists in literature regarding the changes in HR/PR of an animal in response to heat stress. Earlier workers have elucidated that in cattle, short term exposure to heat stress increases HR while long term exposure leads to a decline in HR (Beatty *et al.* 2006; Cowley *et al.* 2015; de Andrade Ferrazza *et al.* 2017). Al-Kanan (2016) also found a decline in HR during high THI levels which was attributed to non-acclimatization to heat stress conditions, that makes the animal to reduce HR/PR to lessen the heat production (Kadzere *et al.* 2002).Contradictory to this, HR increased by 6 beats per min in Holstein dairy cows when THI increased from 68 to 78 (Bouraoui *et al.* 2002). While, Sengar *et al.* (2017) recorded a significant increase in PR of Frieswal bulls, from 66.63 ± 0.57 to 105.60 ± 0.57 when temperature increased from 15–18 °C to 42–45 °C. Banerjee and Ashutosh, (2011) studied the effect of heat exposure in Tharparkar (*Bos indicus*) and Karan Fries cows, subjecting them to heat in a climatic chamber at 38°C temperature and 50–60% RH. The study revealed an increasing trend in PR with increase in heat load with higher PR during the noon period, both in control and heat stress conditions. Thermal exposure lead to higher increase in PR in KF cows compared to Tharparkar cows, in KF the PR increased from 58.17±2.20 beats per minute to 87.67±1.80 beats per minute, while the increase was from 52.17 ±1.35 to 81.83±0.75 in Tharparkar cows, suggesting higher stress in KF cows. Similar findings of higher PR during hotter ambience have been reported in the studies of Bhan *et al.* (2012)**,** Yadav *et al.* (2016) and Kumar *et al.* (2017). The higher PR/HR in response to heat stress is attributed to higher catecholamines released in the body of an animal, that increases the cardiac output in an attempt to dissipate more heat. The difference in cardiac response is noticed in breed differences, that in turn suggests the adaptational variation among cattle breeds. Decline in PR/HR with increased heat load has been mostly encountered in taurine breeds, while most studies on *Bos indicus* revealed an increased HR/PR with increased heat load, suggesting differences in coping mechanism as well as better heat tolerance among indicine breeds.

All the conventional methods of assessing physiological responses in reaction to heat stress are invasive or time consuming or lead to over or under estimation as they require handling and restraint of animals. Non-invasive and non-stress inducing methods are therefore important for precise evaluation of animal stress (Stewart *et al.* 2007). Skin surface is a crucial route of heat exchange, and Skin temperature (ST) is the result of the regulation of this exchange between the skin and core animal body due to blood flow. Skin surface temperature measured at different points of animal has been used by many researchers as a suitable indicator of heat stress in animals (Poikalainen *et al.* 2012), it is an efficient non-invasive way to assess heat stress and can be done by Infrared thermography (McCafferty, 2013). Environmental temperature and THI increase results in concomitant increase in skin surface temperature in animals (Bhan *et al.* 2012; de Lima *et al.* 2013; Singh *et al.* 2014; Grewal *et al.* 2018), even increase in intensity of solar radiation increases the skin temperature ST (Das *et al.* 1997). Furthermore, Amamou, *et al.* (2019) recorded an increase of 0.04°C ST per one unit increase in THI with a 1.3-fold higher ST in Holstein cows in summer period compared to the autumn period. In a comparative study between Tharparkar (*Bos indicus*) and Karan fries (*taurus* × *indicus* crossbreed) the increase in ST from winter to summer was found to be higher in crossbred cows, from 28°C to 43°C against 24°C to 39.07°C (Maibam *et al.* 2017). The same study revealed higher ST in crossbred cows across all seasons as compared to the indicine counterpart. Jian *et al.* (2015) also studied the difference in physiological response among Sahiwal (*Bos indicus*), crossbred (HF50%) and Holstein Friesian (*Bos taurus*) cows. Their study revealed a much higher increase in ST of taurine and crossbred showed in which the ST increased from 32°C to 41°C and from 28 to 37°C, respectively, when THI increased from 72 to 93, at the same time Sahiwal cows showed an increase from 30 to 36°C, only. This indicated a much higher heat load in taurine cows and their crossbreeds. However, few exceptions have been reported where no difference in ST was observed with increase in ambient temperature (Alam *et al.* 2011). Furthermore, significant correlations have been derived between RT and ST by various researchers (Zotti *et al.* 2011; Kumar and Kumar 2013; Yadav *et al.* 2017) and can be used as an alternative to RT to assess the increase in body temperature resulting from heat stress (Yadav *et al* . 2017).

An effort has been made to summarize various studies conducted to evaluate the physiological responses of different cattle types when exposed to range of THI (Table 1). Indicine breeds showed better tolerance in almost all the studies even when subjected to higher THI, while taurine breeds showed higher physiological stress even at relatively lower THI. Various studies covering different season has established that *Bos indicus* breeds have better thermotolerance as compared to their taurine counterparts (Hansen, 2004; Pereira *et al* . 2014). In many countries, the superior thermotolerance capability of *Bos indicus* have been exploited in various crossbreeding programs to develop breed which are both high producing as well as thermotolerant.

Table 1: Physiological responses of *Bos indicus, Bos taurus,* and crossbred cows at different THI

	Cattle breed	THI	Physiological response	References
Bos indicus	Sahiwal	THI = 87.28±1.26	RR- 29.818 ± 0. 795 RT- 38.810 ± 0.095	Sailo et al., (2017)
	Sahiwal	THI = 80.9±2.1	RT- 39.91 ± 0.07 RR- 22.33 ± 0.67 PR- 62.33 ± 0.67 ST- 37.25 ± 0.56	Bhan et al., (2012)
	Tharparkar	THI = 84.34	RT- 38.89 ± 0.03 RR- 17.3 ± 0.11	Bhat et al., (2016)
	Hariana	THI = 86.83 ± 0.76	RT- 38.99 ± 0.03 RR- 28.71 ± 0.68 PR- 69.04 ± 0.44	Kumar et al., (2017)
	Sahiwal		THI = 86.83 ± 0.76 RT- 39.04 ± 0.04 RR- 27.50 ±1.00 PR- 66.88 ± 0.88	Kumar et al., (2017)
	Hariana	THI= 80	RT- 37.88 ST- 28.97 ± 0.55	Kumar et al., (2020)

	Cattle breed	THI	Physiological response	References
	Hariana	THI= 86	RT- 38.61 ST- 43.01 ± 1.16	Kumar et al., (2020)
	Tharparkar	THI= 80.7	RT- 38.88 ± 0.05 ST- 39.07 ± 0.23	Maibam et al., (2017)
	Chinampo	THI ≤ 72	RT- 37.98 ± 0.06 RR- 31.46 ± 0.86	Espinoza et al., (2009)
	Chinampo	THI > 72	RT- 38.66 ± 0.02 RR- 42.43 ± 0.39	Espinoza et al., (2009)
	Australian zebu	THI = 93	RT- 39.05 ± 0.02 RR- 69.5 ± 0.73	Srikandakumar et al., (2004)
Crossbred cows	HF crossbred	Morning THI= 87.33 Noon THI= 78.79	RT- 38.75 RR- 33.27	Gatphayak et al., (2009)
	Jersey crossbred	THI= 71.15 RR- 18.34 ± 1.20	RT- 37.97 ± 0.15	Das et al., (2015)
	CB	THI= 83.2± 2.52	RT- 38.3 ± 0.48 RR- 68.4 ± 1.94	ST- 35.4 ± 1.09Singh et al., (2014)
	CB	THI= 80.9 ± 2.52	RT- 38.33 ± 0.48 RR- 63.0 ± 1.94 ST- 35.7 ± 1.09	Singh et al., (2014)
	Karanfries	THI = 87.28±1.26	RR- 47.299 ± 1.136 RT- 39.186 ± 0.115	Sailo et al., (2017)
	CB	THI = 74.57	RT- 39.14 ± 0.03 RR- 75.94 ± 0.77 PR- 61.64 ± 0.59	Yadav et al., (2016)
Bos taurus	Holstein cows	THI = 73.66 ± 0.07	RT- 38.42 ± 0.03 RR- 36.97 ± 0.81 HR- 64.62 ± 0.79	de Andrade Ferrazza et al., (2017)
	Holstein	THI = 76.59 ± 0.06	RT- 38.67 ± 0.03 RR- 42.06 ± 1.05 HR- 67.62 ± 0.79	de Andrade Ferrazza et al., (2017)
	Holstein cows	THI = 78	RT- 39.18 ± 0.04 RR- 41 ± 0.38 PR- 74 ± 0.27	Bouraoui et al., (2002)
	Holstein cows	THI = 80.7 ± 0.9	RT- 40.1 RR- 80	Perano et al., (2015)
	Holstein	THI ≤ 72	RT- 38.24 ± 0.11 RR- 51.47 ± 2.93	Espinoza et al., (2009)
	Holstein	THI > 72	RT- 39.1 ± 0.06 RR- 68.11 ± 1.47	Espinoza et al., (2009)
	Jersey	THI ≤ 72	RT- 37.87 ± 0.07 RR- 44.05 ± 2.47	Espinoza et al., (2009)
	Jersey	THI > 72	RT- 38.76 ± 0.04 RR- 68.93 ± 1.56	Espinoza et al., (2009)

Cattle breed	THI	Physiological response	References
Holstein	THI = 82	RT- 39.16 ± 0.05 RR- 86.96 ± 1.28 HR- 85.18 ± 0.26	Shapasand et al., (2010)
Jersey	THI = 93	RT- 39.43 ± 0.02 RR- 75.7 ± 0.73	Srikandakumar et al., (2004)
Holstein	THI = 93	RT- 39.65 ± 0.02 RR- 85.3 ± 0.73	Srikandakumar et al., (2004)
Holstein	THI = 77 ± 2.5	RT- 39.3 ± 0.2 RR- 62.7 ± 3.0 ST- 38.4 ± 0.9	Amamou et al. (2019)

RT- °C, RR- breaths/min., HR/PR-beats/min. and ST- °C

CONCLUSION

Most of the research on thermal stress in animals especially in Indian context have focused on recording physiological parameters in response to different levels of heat stress. However, to ensure high welfare standards in animal production, an integrated approach by coupling the cognition of the negative effects of heat stress with amelioration strategies should, wherever possible be considered, for the inherent adaptions of animals.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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