J Anim Behav Biometeorol (2019) 7:104-118 ISSN 2318-1265

REVIEW

Resilient capacity of cattle to environmental challenges – An updated review

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Received: March 15, 2019 ▪ Accepted: April 08, 2019

Abstract Livestock rearing plays an integral role in enabling small and marginal farmers to ensure their livelihood security, which prevents both the food insecurity and poverty. Among the livestock, large ruminants and in particular cattle plays a significant role from economic perspectives. This review is an attempt to compile information pertaining to thermo-tolerance of cattle to heat stress challenges. Heat stress has serious consequences, which negatively influence cattle production causing severe economic burden to the cattle farmers. The ability of the cattle to perform normal biological functions in various adverse environmental conditions denotes its resilient capacity. The resilience capacity is determined by various traits which govern maintaining their body conformation, respiratory and cutaneous evaporative cooling mechanisms, hair coat, maintenance of metabolic rate, feed efficiency, tolerance to dehydration, production maintenance and reproductive efficiency. Breed differences were established for climate resilience and the superiority of indigenous breeds over exotic animals were established in this aspect. The resilience capacity of indigenous cattle based on changes associated with both phenotypic and genotypic traits were reviewed and several biological markers, which reflect the ability of cattle to survive in different climatic conditions, were highlighted. The significance of refining the existing breed program for imparting climate resilience was projected to identify breeds, which have the ability to survive in different agro-ecological zones.

Keywords: adaptation, cattle, climate, heat stress, thermo-tolerance

Introduction

Global livestock is facing immense pressure as per their production is concerned. The demand by the consumers for the livestock products is increasing day by day, which in turn pressurizes the livestock production worldwide. Livestock production is carried out in varied environmental conditions. Climate change poses a serious threat to livestock productivity (FAO 2015). In the future, livestock sector is challenging with projected scarcity of resources for production under climate change. Climate change can have both direct and indirect effect on livestock production. Climate change hampers the livestock productivity directly by altering the homeostasis, adaptive response mechanisms and prevalence of diseases and indirectly by affecting the quantity and quality of feed crops and forages (Bett et al 2017, Giridhar and Samireddypalle 2015).

At the global scenario, 40% of agricultural GDP is contributed by livestock farming. Livestock sector employs 1.3 billion people and supplies approximately one-third of the protein consumed by the human population. Global meat production is projected to more than double from 229 million tonnes in 1999/2001 to 465 million tonnes in 2050 and global production of milk is to double from 580 to 1043 million tonnes (FAO 2010).

Cattle farming activities are socially, economically and politically driven. Cattle rearing have influence and impact on various aspects of the environment. Cattle farming results in the production of three of the four principal gases with global warming potential: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20) (Statham et al 2017). Around the globe, cattle are reared in various agro-ecological zones for varied purpose. Over the years, cattle have developed morphological, behavioural, genetical and physiological adaptation strategies to adjust to their native environmental conditions. Around the globe, we can observe the presence of various cattle breeds in particular to the environmental conditions. Environmental parameters and events have a profound effect on breed evolvement and phenotypic potential with respect to their

doi.org/10.31893/2318-1265jabb.v7n3p104-118

production are concerned. Cattle are mainly reared for milk, meat, hide and manure.

The ability of the cattle to perform normal biological functions in adverse environmental stressors denotes its resilient capacity. The traits denoting the resilience include body surface area, body conformation, sweating rate, extremities, hair coat, maintenance of heat balance, metabolic rate, feed efficiency, tolerance to dehydration, production maintenance and reproductive efficiency. It is worthy to note that, indigenous breeds exhibit more resilient capacity than the exotic breeds due to their inherent capacity to tolerate the stressful condition. Resilience capacity of livestock species can be improved by providing comfortable, non-threatening environment (Rashamol and Sejian 2018).

Cattle and its role in food security

World is facing the challenge of feeding due to the rapid expansion of the human population and food security is the prime global challenge of the 21st century (Kennedy 2014). Food security as defined by the WHO "Ready access to sufficient, safe, nutritious food to maintain a healthy and active life''. Globally, around billion people are facing the burden of food insecurity, among which 20 million children aged <5 years who experience severe malnutrition. Food security is the major cause of disability and death worldwide.

Food insecurity is primarily faced by poor developing countries, in which the majority of the population are involved in farming activities. Most of the farmers are small and marginal holders of the land. Livestock is an integral part of their farming and household activities. To achieve food security, livestock particularly bovines plays a crucial role by providing milk, meat, and income. Livestock products are highly balanced food with respect to their nutrient is concerned. They provide high protein, numerous essential minerals, and vitamins to the world population. Milk and meat are energy dense and acts as complete nutritious food. Livestock products account for the one-third consumption of the protein worldwide. Poor and marginal section of the people depends on animal-source food (especially dairy products) to ensure that their diets deliver the nutrients necessary for cognitive and physical development (Randolph et al 2017).

Livestock rearing plays an integral role in enabling small and marginal farmers to have resilient livelihoods and prevents both food insecurity and poverty. Livestock can contribute up to 33% of household income. Overall, 75% of rural people and 25% of urban people depend on livestock for their livelihoods (Grace 2012). Most of the surge in world population is within developing countries. In recent decades, the consumption of animal meat in developing countries has risen by 5% per year, and milk consumption by nearly 4% per year (Nabarro and Wannous 2014).

Undernutrition hampers cognitive development, school performance, and achievement among the children. This lowered human capital development affects human productivity and combats economic growth. Livestock products are particularly appropriate for combating malnutrition and a range of nutritional deficiencies, as they are energy dense, large protein source and reservoirs of micro- and macronutrients. Livestock production mitigates the effects of large seasonal fluctuations in grain availability by constantly supplying milk, meat, and eggs. Livestock maintains the household well-being complex, as they are part of household production and consumption decisions. Livestock influences the human nutritional and health status in multiple ways such as consumption of livestock products, generation of household incomes, nutrient cycling, providing employment, etc. (Wilson et al 2005; Randolph et al 2017).

Environmental stresses affecting production and reproduction in cattle

Environmental factors such as ambient temperature, relative humidity, solar radiation, and wind speed combine and interact to form "Heat stress", which often limits the cattle performance in terms of its production and reproduction aspects. Heat stress results due to increased air temperature and temperature-humidity index (THI). Heat stress leads to unavailability of feed and fodder for the cattle as well as reduces the dry matter intake (DMI). Environmental temperature above 35°C elicits stress mechanisms in lactating dairy cows. It is worthy to note that high producing dairy cattle generates high metabolic heat than low producing animals. Hence, high producers are more prone to heat stress (Angel et al 2018).

Milk production

Milk quantity and quality is affected by the hot and humid climate. As saliva production and respiration rate increases which are linked to a significant decrease in milk production (Collier, 1985). During the dry period, mammary epithelial cell proliferation is affected by the heat stress leading to reduced milk production. Apart from reduced dry matter intake, altered carbohydrate and fat metabolism also affect milk synthesis and secretion. Rumen fermentative mechanism is altered during heat stress, in which acetate production is decreased leading to inappropriate acetate: propionate ratio which leads to reduced milk fat yield (Collier 1985, Baumgard and Rhoads 2013).

Severity of the heat stress over the cattle production and reproduction is attributed to various factors such as; actual temperature and humidity, length of the heat stress period, size of the cow, degree of night cooling, housing, size of the cow, production potential, breed, coat colour, hair coat and water availability (Chase 2006). All climatic factors lead to variation in the composition and production of milk. Winter season is the favored environmental season for the milk production by dairy cattle and buffalo (Barash et al 2001). Milk quality is highly affected during summer heat stress. The protein portion showed a reduction in percentages of casein, lactoalbumin, IgG and IgA (Kadzere et al 2002).

Beef production

Compared to dairy cattle, beef cattle are less affected by heat stress. It is due to reduced body surface area to mass ratio, decreased rumen heat production and reduced overall metabolic heat production. Further, beef cattle shows the compensatory weight gain after mild or short periods of heat stress (Mitlohner et al 2001). Beef cattle experiencing heat stress exhibits changes in energy and nutrient metabolism, which affect their heat tolerance and production parameters, such as lean tissue accretion. Skeletal muscle constitutes the large proportion of animal mass and has a profound effect on whole-animal energy metabolism and nutrient homeostasis especially during periods of heat stress (Rhoads et al 2008).

Microarray analysis of skeletal muscle gene expression reveals dramatic changes in the skeletal muscle transcriptional profile relating to mitochondrial function in chronic heat stressed cattle. It signifies heat-stressed bovine skeletal muscle have mitochondrial dysfunction leading to impaired cellular energy status. Finally, it results in reduced growth. Beef cattle better tolerate heat stress than dairy cattle as meat synthesis does not rely on glucose to the extent that milk production does. (Collier et al 2008).

Reproduction

During the hot and humid summer months, heat stress disrupts reproductive processes in dairy cows worldwide. Increased body temperature in summer is responsible for impaired reproduction. During summer, conception rate decreases between 20 and 30% compared to the winter season. Heat stress is responsible for the low fertility of dairy cows inseminated in the summer months. Thus, it is clear that the reproductive system is highly susceptible to thermal stress (De Rensis and Scaramuzzi 2003).

Heat stress compromises the intrauterine environment in cows, blood flow is decreased to the uterus and uterine temperature is increased. These unfavorable environments inhibit embryonic development, increase early embryonic loss and reduce the conception (Roman-Ponce et al 1978). Thermal stresses also affect the follicular dynamics in which it delays follicle selection and lengthens the follicular wave and thus have adverse effects on oocytes quality and follicular steroidogenic machinery (Roth et al 2001).

In heat-stressed dairy cows, dry matter intake is reduced. It leads to a negative energy balance. Negative energy balance leads to decreased plasma concentrations of insulin, glucose, and IGF-I, and increased plasma concentrations of GH and non-esterified fatty acid. These alterations in hormonal milieu affect reproduction. Insulin is essential for follicular development and has beneficial effects on oocyte quality. IGF-I and glucose have stimulatory effects on follicular growth and implantation and glucose is a primary source of fuel for the ovary. Glucose also modulates the LH secretion and in turn ovulation, therefore severe hypoglycemia inhibits pulsatile LH secretion and prevents ovulation. In addition, temperature sensitive prolactin level is increased in summer and it inhibits follicular development (Lucy et al 1992; O'callaghan and Boland 1999).

Heat stress impairs the cellular and molecular mechanisms in oocytes. Exposure of oocytes to thermal stress leads to derangements of microtubules and microfilaments (Roth and Hansen 2005), arrest at metaphase I (MI) stage and damaged spindle apparatus. Fragmented DNA, reactive oxygen species (ROS), apoptotic genes are increased in oocytes exposed to heat stress (Ferreira et al 2016; Wolfenson and Roth 2018).

Heat stress not only affects the early embryonic growth but reduces embryonic growth until the maternal recognition of pregnancy. An adequate amount of interferon tau must be secreted from the embryo to prevent the luteolysis and to maintain the pregnancy. However, heat stress reduces the size of embryos as well as interferon-tau secretion. Further, heat stress enhances the endometrial secretion of PGF2α leading to the luteolysis. Collectively, heat stress affects the embryo survivability in the intrauterine environment and thus disrupts the maternal recognition of pregnancy and further reduces the pregnancy rates (Putney et al 1989).

Thermal stress hampers bull fertility in the hot and humid summer. Heat stress reduces the sperm concentration, semen volume, lowers sperm motility and increases the morphologically abnormal spermatozoa in the ejaculate. Heat stress alters the length of the spermatic cycle and thus affects the fertility in bull (Collier et al 2008). In the hot summer season, germinal epithelial degeneration occurs leading to decreased scrotal circumference, size and weight. The thermoregulatory mechanism of the testes, sexual desire (libido) and live sperm percentage are negatively affected (Hansen 1997).

Thus, high summer temperature above the thermoneutral zone of cattle drastically increases the embryonic loss and hampers the conception rate. Heat stress also deteriorates the bull fertility and hence fertility is reduced during summer. Thermal stress also adversely affects the ovum and sperm in the reproductive tract and early embryo development.

Different adaptive mechanisms of cattle

Morphological adaptation of cattle

Morphological characters of livestock are very vital for the adaptation of animal during the stressful condition as they directly influence the heat exchange mechanisms such as cutaneous convection, radiation, and evaporation between the animal and the surrounding environment (McManus et al 2009). Morphological adaptation includes coat color, fur depth, hair type, hair density, fat storage in hump or tail, skin color and body size (Khalifa 2003). Morphological alteration is one way of adaptation during the harsh environment (Barendse 2017). During heat stress, cattle exhibit some morphological changes, which include larger salivary glands, higher surface area of absorptive mucosa and the ability to increase the considerable volume of the foregut when fed with high fibrous food (Silanikove and Koluman 2015).

The main features of the animal that affects the efficacy of evaporative heat loss from the skin surface are the sweat gland density, function, and morphology, hair coat density, length, color and regulation of epidermal vascular supply (Collier et al 2008). The coat color is the important morphological adaptive trait, which imparts adaptive ability to livestock during heat stress exposure. The dairy cattle from the tropical condition have lighter colored hair coat, which protects the animal from the solar radiation (Fanta 2017). The white or light coat color might help the animal to reduce the direct effect of heat stress by reflecting more incident solar radiation from the body (Katiyatiya et al 2017).

Light colored skin protects the tissues from direct short wave UV radiation by blocking its penetration to the animal’s body. The light colored coats help to reflect 50% to 60% of direct solar radiation than the dark-colored animal (McManus et al 2009). Naguni breed is multi-colored indigenous cattle, which produce optimum under hot and tropical environment condition (Mwai et al 2015). Animals with black color require more water to reduce heat stress condition than the light colored cattle. In a study, it was observed that the cow with lighter colored coat showed lesser shade-seeking behavior than the darker one (Tucker et al 2008).

Cutaneous evaporation is recognized as the most important mode of heat dissipation in cattle (Jian et al 2016). Presence of smooth, light, short and thin hairs in cows help to enhance maximum heat dissipation during thermal stress conditions (Fanta 2017). Thicker hair coats and increased deposition of subcutaneous fat insulate the body core temperature, which increases the heat stress effect during the summer season. Further, coat length, thickness and hair density also affect the adaptive nature of animals in thermal stress, where short hair, thin skin and fewer hair follicles per unit area are directly linked to the higher adaptive capacity to hotter climate.

Coat type is a multifactorial trait, which helps the animal to cope with stressful condition (Olson et al 2003). The gene that causes substantial changes in the coat type is generating a slick phenotype that improves heat tolerance in stressful condition (Carlson et al 2016). Research findings indicated that slick gene induced in the animal could regulate the body temperature affecting hair length (Mariasegaram et al 2007). Despite these, Dikmen et al (2008) conducted a study inducing slick hair gene to Holstein cows that rendered its carrier with a silk hair coat and improved their thermo-tolerance ability of the animal.

Declined body size is one of the universal responses to warming beside variations in phenology and dissemination (Gardner et al 2011). Smaller body size of tropical indigenous cattle breeds is beneficial for surviving in harsh environments (Sejian et al 2018). In addition, changes in functional traits like body size have a significant consequence on thermal biology and energetics of ruminants, as body size directly affects energy requisite for maintenance, growth, and production (Mitchell et al 2018). A study showed that dwarf breeds of cattle use different heat tolerance mechanisms than standard cattle breeds, making them better adapted to hotter climates (Martin et al 2018). The standard cattle breeds acclimatize to the warm environment through physiological, biochemical and molecular changes while the dwarf breeds have adapted through changes in their genes (Elayadeth-Meethal et al 2018). In addition, indigenous cattle breeds also possess efficient testicular thermoregulatory mechanisms during heat stress conditions through higher ratios of testicular artery length and volume of testicular tissue (Brito et al 2004).

Behavioral mechanisms of cattle

Behavioral responses are the primary adaptive mechanism by which animals try to decline the heat load from their body during the exposure to the heat stress condition. The behavioral variable is recorded manually using stopwatch by closely observing the animals continuously for 6 hours. Currently, several other advanced technologies are also available such as photographs, video recording and other sophisticated instruments like Global Positioning System (GPS), GPRS, etc which made the recording much easier. The most important behavioral responses in dairy cattle include shade-seeking behavior, standing time, lying time, water intake, feeding, defecating and urinating frequency and drinking frequency (Ratnakaran et al 2017).

One of the profound behavioral responses the animal exhibit during heat stress is shade-seeking behavior. Placing a simple shade over the animal exposed to direct solar radiation may reduce the heat load of about 45% (Kamal et al 2016). Shade seeking behavior is an attempt of the animal to ameliorate the direct negative effects of heat load during heat stress exposure. Blackshaw and Blackshaw (1994) reported that the cows using shade during warm summer showed lower core body temperature and respiration rate as compared to those animals without shade. Similarly, Curtis et al (2017) reported that the dairy cattle seeking shade during heat stress increased their feed intake with high air temperature and solar radiation. However, tropical indigenous breeds were observed to be highly adapted to direct heat stress, spending more time for grazing than resting in shade (Sejian et al 2018).

Increased standing and decreased lying time was also reported as an adaptive mechanism to be associated with higher and prolonged ambient temperatures (Provolo and Riva 2009). Heat-stressed animal spend more time in standing posture in order to reorient themselves in different directions to avoid direct solar radiation and ground radiation. During thermal stress, animal upsurge evaporative heat loss in order to reduce the excess heat load from the body surface and assist in convection by standing more time to get away by the conductive and radiative heat from the surroundings (Kamal et al 2016; Sejian et al 2018). Even mild heat stress also result in increased standing time which may lead to lameness in cattle, when the animal stands for more than 45% per day (Tucker et al 2008). A study by Kim et al (2018) observed a significant decrease in lying time and increase in standing position in heat stressed beef calves. Further, they also reported that the rumination was decreased with increased temperature. The reduced lying time due to heat stress, alter the physiological response, which may eventually have a negative impact on the health status of cattle (Schutz et al 2010). Further, reduced lying time may also result in a drop of milk yield (Bach et al 2008).

The cattle exposed to the harsh environment tend to increase their water intake to restore the higher fluid loss from the body through respiratory and cutaneous evaporative cooling mechanism. Apart from maintaining the body water status, upsurge in water intake also helps the animal to withstand the heat stress condition by immediate rumen-reticular cooling which reduces their core body temperature effectively (Garner et al 2017). The frequency of water intake per day also increased in hot and dry climatic conditions (Machado et al 2004). Markwick (2002) has reported the 40% increase in water consumption during warm summer than the winter season. Increased drinking frequency and water intake were reported for Angus and Nellore bulls during exposure to summer heat stress (Valente et al 2015). Similarly, Coimbra et al (2010; 2012) also observed increased water intake during the exposure to harsh environmental conditions.

Reduced feed intake is another important mechanism animal adopts to cope with the stressful condition (Sejian et al 2018). In lactating cows, the feed intake started declining at the temperature 25-26ºC and rapidly decreased at 30ºC (Rhoads et al 2013). The reduction in the feed intake during hot climate helps the animal to reduce the metabolic heat production and the body weight and the body condition score will go down due to this negative energy balance (Brscic et al 2007).

Heat stress plays a crucial role in affecting the urination and defecation frequency of the animal. Non-pregnant dry Holstein cows showed a significant decline in urine output along with the rise in urinary sodium excretion and a significant reduction in serum sodium during heat stress exposure (El-Nouty et al 1980).

Wallowing is another behavioral response that protects the animal from direct solar radiation and provides a cooling effect, especially in buffaloes. It improves the productive performance as well as the welfare of the animal (Somparn et al 2006). The greater amount of wallowing exhibited during the sunrise and sunset hours. During heat stress, wallowing lowered the body temperature of buffaloes better than that of spraying water on the body surface.

Physiological mechanisms of cattle

Exposure of animals to heat stress induces an increase in the dissipation of excess body heat to the environment to reduce the heat load in their body (Collier et al 2018). Some of the physiological determinants of adaptations to heat stress are the respiratory rate (RR), rectal temperature (RT) and pulse rate (PR) (Indu et al 2015). Further, the physiological responses are affected in a day due to the change of environmental variables drastically in a day. In addition, the physiological responses generally increase from the morning (07:00 a.m. - 10:00 a.m.) till noon (11:00 a.m. - 02:00 p.m.). And values of physiological variables remain stable during (11:00 p.m. - 06:00 a.m.) period because these responses begin to drop from evening till night time (da Silva et al 2017).

Respiratory rate

The RR act as an early warning signal and ideal biomarkers of heat stress condition in livestock. The animal's evaporative cooling mechanisms get activated through the process of multifold increase in RR (Indu et al 2015). Further, increased RR is exhibited by cattle exposed to increased ambient temperature and relative humidity (Rashamol et al 2018). In addition, a comparative study by Sailo et al (2017) revealed that the RR was 15.738±0.795, 18.158±0.795 and 29.818±0.795 in Sahiwal and 15.779±1.136, 22.979±1.136 and 47.299±1.136 in Karan Fries cattle during winter, spring and summer seasons respectively. This report indicates that with an increase in THI there was increased RR in both Sahiwal and Karan Fries cattle (Sailo et al 2017). Research by Valente et al (2015) revealed that heat stress in Angus cattle showed significant higher RR (104 breaths/minute; 37.7ºC). Recently, Balamurugan et al (2017) reported that respiration rate acts as an indicator of heat stress in the hot environment and was in correlation with circulating corticoids concentration.

Rectal temperature

Increase in RT in heat stressed animals is a natural mechanism to dissipate extra heat load to maintain homeostasis (El-Tarabany et al 2017). Importantly, RT is one of the physiological traits associated with heat stress in farm animals (Rashamol et al 2018). Sailo et al (2017) reported that Sahiwal RT (°C) were 37.300±0.095, 38.178±0.095 and 38.810±0.095, while in Karan Fries 37.492±0.115, 38.398±0.115 and 39.186±0.115 during winter, spring and summer respectively. This suggests that with increases in THI there was increased RT in both Sahiwal and Karan Fries breeds. A research study by Chandra Bhan et al (2013) also suggests that, a direct correlation between RT, humidity and other physiological traits in Murrah buffaloes and Karan-Fries cattle. Findings from these reports indicate that RT may be considered as another reliable biological marker for quantifying heat stress response in domestic livestock. Indigenous zebu breeds (Gir, Sindhi, and Indubrasil) showed a higher magnitude of RT and heart rate in the afternoon (35.9°C) (Sejian et al 2018). Some studies reported that the rectal temperature of buffaloes was always less than to cattle during summer months under high and low humid conditions (Ganaie et al 2013). The rectal temperature was higher during summer (39.83°C) than autumn (38.30°C) in lactating cows (Ganaie et al 2013). Added to that, lactating cows exhibited a higher respiration rate of 71.5/minute during summer compared to 38.8/minute in winter (Ganaie et al 2013) and also found that increased ambient temperature increases ventilation rate of cattle and buffaloes significantly. Certainly, the rise in air temperature appeared to be the major cause of the increase in body temperature and respiration rate of dairy cows (Ganaie et al 2013).

Pulse rate

The PR is a reflection of circulation along with the general metabolic status (Rashamol et al 2018). PR acts as a reliable indicator of livestock in adverse environmental conditions (Das et al 2011). According to Al-haidary (2004), the daily average Heart Rate (HR) decreases during heat stress state with 115.7 and 85.8±11 beats/min for the control and heat stress groups, respectively. HR was increased during the peak hour of the heat load (15:00) in cattle. Popoola et al (2014) and Rashamol et al (2018) also reported a correlation between HR and metabolic heat production.

Skin temperature

As temperature of animal increases, the vasodilation of skin capillary bed and the blood flow to the skin surface also increases to facilitate heat dissipation in animal (Katiyatiya et al 2017). A skin surface thermocouple probe connected to a microprocessor-based handheld thermometer is used to measure ST in different parts of the body (back, flank and forehead). Generally, summer season induces higher ST. In summer day, the ST was lower at 8:00 h than at 12:00 h and 16:00 h (Rashamol et al 2018). In addition, the ST was increased by 0.22 °C in animals per extra degree of ambient temperature exposure (Paulo and Lopes 2014).

Sweating rate

Excess heat dissipation from the body through cutaneous evaporative cooling mechanisms is known as sweating (Rashamol et al 2018). Importantly, dairy cattle use evaporative cooling as the dominant mechanism to dissipate heat when exposed to high quantum of heat stress (Gebremedhin and Wu 2001). Moreover, sweating is influenced by weather parameters such as wind velocity, air temperature, relative humidity, and thermal and solar radiation. As well as morphological characteristics that affect the efficacy of evaporative cooling from the skin surface are fur or hair coat, density, and thickness of hair coat, hair length and both hair and skin color (Gebremedhin et al 2008). According to Hillman et al (2001) study, higher sweating rate was recorded in black cows (800 W/m^2) than white cows (500 W/m^2). Higher reflection was exhibited in light hair coats than dark hair coats having wavelengths ranging from 300 to 850 nm (da Silva et al 2003). Another study by Hillman et al in 2005, results suggest that heifers exhibited an increase in sensible heat flux under sunlight in the order of 26% for dark-red, 22% for black, 5% for tan, and 4% for white coat color (Hillman et al 2005). This study also concluded that the heat gain was higher for heifers with dark (Black Angus) and dark red (MARC III) hair coats than those with white and tan hair coats (Rashamol et al 2018). These physiological adaptations are very much essential to maintain normal body temperature and prevent hyperthermia under extreme climatic conditions (Rathwa et al 2017).

Blood biochemical changes in cattle adaptation

The blood biochemical composition is directly proportional to the health status of the cattle and these can be used as an index for assessing the adaptation capacity of cattle to climate. Generally, heat stress causes alteration in blood biochemical parameters. Heat stress causes an increased level of hemoglobin and packed cell volume in cattle and these changes are due to adaptive characteristics to heat stress condition (Gaughan et al 2018). In addition, increased temperature of animal results in impaired erythropoietin (Patel et al 2016). Further, hematological parameters, namely, red blood cell, hemoglobin, and packed cell volume are significantly higher and different among the heat stressed Tharparkar and Karan Fries heifers breeds, whereas no significant changes are observed in total leukocyte count and differential leukocyte count (Pandey et al 2017).

Heat-stressed cattle showed a significant increase in plasma albumin level (Calamari et al 2018). Likewise, plasma albumin level was higher in Holstein heifer exposed to summer than winter season (Angel et al 2018). Heat-stressed dairy cattle showed a decreased level of NEFA in plasma. This could be attributed to the high requirement of NEFA in the liver and peripheral tissues as a source of energy (Skibiel et al 2018). However, Shehab-Ei-Deen et al (2010) opined that the NEFA concentration increases with the exposure to summer and this can be related to the adaptive capability of the cattle to maintain constant energy throughout the hot season.

Alberghina et al (2013) also suggested a decreased level of total serum cholesterol in heat-stressed dairy cows. Furthermore, heat-stressed cows and heifers (Bernabucci et al 2010) showed increased plasma urea nitrogen levels compared with the thermal neutral controls. The primary indicator of muscle catabolism in circulation is either 3-methyl-histidine or creatine, both of which are increased in lactating cows (Bernabucci et al 2010).

Studies have shown that heat stress causes oxidative stress in transition dairy cows. Under heat stressed condition, cattle exhibit increased levels of superoxide dismutase and glutathione peroxidase, which are indicators of oxidative stress (Bernabucci et al 2002). Moreover, antioxidants levels got impaired under heat stress state such as enzymatic (SOD, CAT, GPX), non-enzymatic (Albumin, L-cysteine, homocysteine, and Protein sulfhydryl groups) and non-enzymatic low molecular weight antioxidants (ascorbic acid, glutathione, uric acid α-tocopherol, β-carotene and retinol) (Balamurugan et al 2017).

A significant positive correlation of THI with the erythrocyte catalase activity in Murrah buffalo and Karan Fries cattle was established. The highest increase in catalase activity was registered in Karan Fries followed by Murrah buffaloes (Ganaie et al 2013). Further, Chandra and Aggarwal (2009) also reported prepartum crossbred cows showed higher catalase activity in summer season (159.94 ± 0.10 μmol/min/mgHb) compared to winter season (153.85 ± 0.08 μmol/min/mgHb).

The levels of enzymes in serum reflect the metabolic activities of individual. Heat-stressed animals showed significantly reduced levels of alkaline phosphatases (ALP) and lactic dehydrogenase (LDH) activity. It is due to decreased activity of thyroid (Ganaie et al., 2013). Added to that, aspartate transaminase (AST) levels were significantly lowered in heat-stressed dairy cows (Ikuta et al 2010). In addition, heat-stressed dairy cows showed higher levels of AST in spring and winter compared to summer and autumn, whereas ALT values were higher in spring than in winter and autumn. The increased activity of these enzymes is due to the leakage of these enzymes from the liver cytosol into the blood stream, which reflects liver damage and disruption of normal liver function (Cerutti et al 2018).

Heat-stressed buffalo heifer showed decreased alkaline phosphatase (ALP) activity (Angel et al 2018). The blood pH increased with increase in temperature and CO_2 levels and was significantly higher than control conditions in Tharparkar and Karan Fries heifers breeds (Pandey et al 2017). Again, the rumen pH decreases due to increased levels of volatile fatty acids in rumen because of lower absorption due to less blood supply (Bernabucci et al 2010).

Endocrine responses of cattle

The continuous exposure of animals to various environmental challenges results in persistent physiological responses to maintain homeostasis, which triggers neuroendocrine responses (Sanin et al 2015). The activation of neuroendocrine system regulates energy mobilization, environmental perception, availability of glucose in the brain, enhancement of cardiovascular and respiratory functions, immuno-modulation, reduced productive and reproductive performance. The response of neuroendocrine system of heat stressed animals varies from release and activation of many tropic hormones such as adrenocorticotropic hormone (ACTH), thyrotrophic hormone (TSH), growth hormone (GH), follicle stimulating (FSH) and luteinizing (LH) hormones and prolactin (PRL) (Minton 1994; Sheba et al 2012).

The primary physiological responses of stress are facilitated by the sympathoadrenal system and hypothalamo-pituitary-adrenal (HPA) axis. The sympathetic nervous system is involved in animal adaptation to environmental stressors and in maintaining the homeostasis (Agrawal et al 2013). The stimulation of sympathoadrenal system reduces blood flow to gastrointestinal system and reproductive organs, which increases the energy mobilization to the brain, heart, and muscles (Mancuso et al 2010). This response initiates the rapid retrieve of homeostasis and enhances the ability for fight or flight reaction to ensure survival by the release of catecholamines (Goto et al 2007; McEwen 2007). The HPA axis is a neuroendocrine system which is highly essential to initiate physiological and endocrine responses to the environmental stress by its relationship with brain serotonergic, noradrenergic and dopaminergic systems (Minton 1994; Sanin et al 2015). The HPA axis responds to the changes in environmental conditions by the peripheral nervous system which are integrated in the central nervous system where paraventricular nucleus of the hypothalamus is stimulated to release corticotropin releasing hormone (CRH) (Carlin et al 2006; Sheba et al 2012; Bova et al 2014). CRH is released into the hypothalamus-hypophyseal portal system to initiate the synthesis and secretion of ACTH, which acts on adrenal cortex to synthesize and secrete cortisol (Steptoe et al 2007; Pavlovic et al 2008). The increase in the level of plasma glucocorticoids occurs with tens of minutes after initiation of stress (Ulrich-Lai and Herman 2009). Cortisol directly influences metabolism and behavioral response of heat stressed animals by favoring glycogenolysis, lipolysis, and proteolysis to supply required energy to restore homeostasis.

The antidiuretic hormone (ADH) is an important hormone for water homeostasis, which aids in water conservation during heat stress. The continuous water losses during heat stress via sweating and evaporative cooling activates the baroreceptors and hypothalamic osmoreceptors to induce ADH release to avoid dehydration (Farooq et al 2010; La Salles et al 2017). Further, the hypovolemia as a result of dehydration during heat stress also activates the renin-angiotensin-aldosterone system which is highly correlated with the maintenance of electrolyte homeostasis. The reduced blood flow to the kidney stimulates the secretion of renin that in turn increases the production and release of angiotensin and consequently the aldosterone (Balamurugan et al 2017). El-Nouty et al (1980) and Schneider (1990) reported that the dehydration during heat stress decreases the plasma volume due to redistribution of water to the tissue to maintain fluid balance by the increased secretion of aldosterone and cortisol. The increased level of aldosterone facilitates reabsorption of water and ions particularly sodium in the kidney to avoid electrolyte loss (Kim et al 2009). Another multi-functional hormone, prolactin (PRL) is believed to be involved in water metabolism in heat-stressed dairy animals. PRL level increases in dairy cattle during heat stress to meet the higher demand for water and electrolytes (Alamer 2011). Whereas, Beede et al (1982) and Collier et al (1982) reported that the increase in PRL concentration may be involved in potassium and sodium turnover during thermal stress.

The secretion and release of tropic hormones are affected by heat stress and leads to reduced thyroid-stimulating hormone. The increase in ambient temperatures inhibits the metabolic hormone secretions such as triiodothyronine (T3) and thyroxine (T4) to avoid thermogenesis (Kahl et al 2015). In addition, T3 secretions are decreased due to the elevated levels of glucocorticoids that inhibit biotransformation of T4 into T3 (Sanin et al 2015). Thyroid activity decreases in heat stressed animals and the reduction in thyroid hormone level is highly associated with a decrease in metabolic rate and a reduction in cellular heat production (Beede and Collier 1986; Silanikove 2000). Further, Pereira et al (2008) reported that cattle breeds with lower concentration of T3 are associated with the capability of heat tolerance. Therefore, reduction in thyroid hormones may reflect an adaptation mechanism during heat stress in order to reduce the metabolic heat production (Bernabucci et al 2010). In stressed cattle, growth hormone (GH) level decreases as a result of reduced feed intake and metabolic adjustments. In addition, the reduction in GH level under heat stress could be due to thermal inhibition of the hypothalamus or lowered feed intake and metabolism (Johnson 1985). The abundance of hepatic growth hormone receptor also decreases along with downstream signal transducer and activator of transcription of phosphorylation. Farooq et al (2010) revealed that the GH level decreased in the milk of heat-stressed lactating cows as means to reduce the calorigenesis to sustain the core body temperature. The down-regulation of GH signaling in the liver could be the reason for the lower production of insulin-like growth factor 1 (IGF1) under heat stress (Rhoads et al 2009; Rhoads et al 2010). Aggarwal and Upadhyay (2013) also reported that the concentration of IGF-1 decreases during heat stress in cattle.

Heat stress also impacts the reproduction of cattle by disrupting the release of gonadotrophin-releasing hormone (GnRH) from hypothalamus, luteinizing hormone (LH) and follicle stimulating hormone (FSH) from the anterior pituitary gland (Khodaei-Motlagh et al 2011; Etim et al 2013). The activation of HPA axis during heat stress inhibits the secretion of hormones from the hypothalamic-pituitary-gonadal (HPG) axis in livestock (Krishnan et al 2017). The corticotropic releasing hormone (CRH) inhibits the gonadotropin-releasing hormone (GnRH) in the hypothalamus (River and Rivest 1991). Masoumi and Derensis (2013) reported that CRH also prevents the ovarian steroidogenic activity thereby decreases the secretion of LH and estradiol. Further, heat stress interferes with the release of FSH and LH in the anterior hypophysis (Khodaei-Motlagh et al 2011). Gilad et al (1993) reported that the exposure of cattle to heat stress substantially reduces the concentration of GnRH-induced FSH secretion. However, tonic FSH secretion is increased which could be due to insufficient inhibitory effect of negative feedback from small follicles (Roth et al 2000). Heat stress causes early atresia of medium-sized follicles as an effect of lowered production of oestradiol from the granulosa cells and increased progesterone concentrations in the follicular fluid of heat-stressed cows (Roth et al 2000). The oestradiol levels decreased in heat-stressed dairy cows, which are consistent with reduced LH and decreased dominance of the selected follicle (Rosenberg et al 1982; Wolfenson et al 1995; Wilson et al 1998). Singh et al (2013) revealed that hyperprolactinaemia as an effect of heat stress inhibits the secretion of FSH and LH at hypophyseal level. The heat stress induces an increase in prostaglandin E2 and prostaglandin F2α secretion in bovine endometrial may disrupt the normal estrous cycle and cause infertility in cows during summer (Sakai et al 2018).

Cellular and molecular changes of cattle adaptation

It is the cellular and molecular changes in a single cell that determine the adaptation of an animal when placed under environmental changes. The commonly faced environmental challenges include heat stress (HS), nutritional stress, water stress, walking stress or combined stress, especially by the grazing cattle.

The Heat Shock Proteins (HSPs) are the common proteins that are expressed at a higher level during various environmental changes. Comparison of Holstein Friesian, Sahiwal and Murrah buffalo during both summer and winter season showed that Sahiwal cows are more thermo-tolerant based on minimum changes exhibited by Peripheral Blood Mononuclear Cells (PBMCs) HSP90, HSP70, HSP60 and HSP40 mRNA expression along with higher cell proliferation assay indicating the better adaptability of indigenous breeds to the tropical heat load condition (Kishore et al 2016). Similarly, comparison of the three breeds Holstein Friesian, Sahiwal and Murrah buffalo heifers during summer, winter, and spring season showed an increase in HSPA1A, HSPA1B, HSP10, HSP60 and HSP90 mRNA expression in all the three breeds during summer and winter season compared to spring. The mRNA expression pattern of HSPs was least in Tharparkar followed by Sahiwal and was highest in Murrah buffalo, while the HSF-1 was highest in Murrah buffalo followed by Sahiwal and Tharparkar during summer and winter season (Kumar et al 2015). The male Tharparkar cattle subjected to heat stress at 42ºC for 23 days showed a significant increase in the both HSP70 mRNA as well as serum extracellular HSP70 expression (Bharati et al 2017). The Tharparkar bull during summer and winter season did not show any significant changes in the mRNA HSP70, HSP90 expression pattern in their semen. Hence, the semen can be collected during any part of the year indicating the environmental tolerance of the indigenous breed of cattle (Rajoriya et al 2014). Polymorphism study in 64 Tharparkar cattle indicated that the animals with allele A had a positive effect and the genotype AA had superior heat tolerance ability in the HSP 70 gene sequence along with positive correlation with thermo-tolerance capacity (Bhat et al 2016). Sahiwal and Karen-Fries exposed to different weather showed an increase in PBMC HSP72 mRNA expression at low THI 55.5 as well as at higher THI 79 (Mayengbam et al 2016).

Under in-vitro conditions, the immature as well as matured bovine oocytes synthesised HSP68 and HSP70 and HSP71 at 39 °C, however at 42 °C they did not synthesis the above said proteins. But in the two-celled embryos, more amount of HSP68 was synthesized at 39 °C slightly at a higher level compared to HSP70 and HSP71, and the expression of HSP68 even increased higher at 42ºC (Edwards and Hanse 1996).

In Holstein calves in response to heat stress, various prominent pathways that showed changes were the heat stress cellular response, phosphorylation, co-chaperones, chaperones, kinase activation, cell cycle, and signaling pathway and protein processing in the endoplasmic reticulum. Immune-related pathways that were altered include MAPK signaling pathway, interferon signaling, B cell receptor signaling pathway, TNF signaling pathway, apoptotic pathway, TLR pathways, antigen presenting pathway, Pi3K/AKT activation, estrogen signaling pathway, JNK signaling pathway, NFκB pathway and pathways in cancer (Srikanth et al 2017).

Breeding cattle for climate resilience

Livestock genetic potential and diversity are critical and essential for food security and livelihood. A breed consists of animals having similar characteristics particular to geographical region and origin. Animal genetic pool allows farmers to select and develop new breeds responsive to changing environmental conditions including climate change, disease resistance, human nutritional demands and societal needs (Hoffmann 2010). Genetic mechanisms determine animal’s fitness and adaptation. According to Barker (2009), adaptation is the state of being adapted, the ability of breeds to produce and reproduce in a given set of environments, or the choice of particular breeds for specific environments. Adaptability is the measure of potential or capacity to adapt. Adaptation traits are less heritable. However, adaptation traits may express when the environment changes (Hill and Zhang 2009).

Breeding climate resilient cattle for climate change adaptation and mitigation is similar to existing breeding programmes. Past breeding programmes aim to improve production, longevity and functional traits simultaneously broadening selection indices (Wall et al., 2008). Along with these traits, climate resilience mainly for heat tolerance has to be considered. Rectal temperature and temperature–humidity index (THI) serves as important tools for selecting heat tolerant cattle (Hoffmann 2010).

Climate-resilient bovine herd management is highly challenging, as to balance the production while maintaining fertility, udder health, and resistance to metabolic diseases in order to maximize profit without compromising welfare. Climate change disrupting global environment emphasis on novel traits that optimize resource use efficiency. Cattle productions should aim at reducing greenhouse gas emissions throughout the production cycle, increasing production efficiency and reducing wastage using novel technologies (Egger-Danner et al 2015).

Cattle breeding goal should consider the following criteria: higher production of milk/beef leading to higher economic returns; reduced input costs in terms of better fertility, fewer diseases, reduced culling rates; ease of management; and advantages in terms of market opportunities. Complex breeding plans also consider a wide range of relevant traits that can be measured economically. In dairy cattle, these traits include efficiency, health, fertility and functional conformation (Bo 2009). Recent biotechnological advancements like transcriptomics, genome sequencing, proteomics, and metabolomics are highly useful for determining the genetic architecture of traits and in turn lead to a better description of phenotypes and enhances selection opportunities (Egger-Danner et al 2015).

External climatic stimuli interact with responding animal genotypes to determine the level of performance. All animals respond to changing natural environments by altering phenotype and physiology. During food scarcity, adaptation occurs by developing low metabolic requirement, ability to reduce metabolism, digestive efficiency and ability to utilize high-fiber feed and deposition of nutrients in the form of fat as feed reserve. Zebu cattle extensive adaptive mechanism to severe hot climates attributes to their unique genetic attributes such as to coat, hide, skin, hematological characteristics, form, growth, and physiological aspects. In livestock, genetic potential with respect to disease resistance is important as disease-causing organisms evolve continuously and develop resistance to drugs. If the herd is infected with new disease or new pathogen, animals with potential diverse genetic material will survive and get least affected. (Turner 1980, Mirkena et al 2010).

There is a negative correlation between production and fitness-related traits, such as reproduction and health. During the negative energy balance condition in lactating cows, poor body condition scoring is evident resulting in decreased fertility (Pryce et al 2000). Energy diverted for production cannot be utilized to other body functions, resulting in disease and fertility problems (Collard et al 2000). In natural conditions, resource allocation for maintenance and fitness is the priority whereas, in human interventions, production gets first priority in resource allocation. An insufficient proportion of resources allocated to fitness may result in decreased health, fertility, and energy available for maintenance, with consequences for reproduction rate and the probability of survival (Van der Waaij 2004).

Therefore, it is important to identify the most adapted genotypic breed capable of coping with environmental stressors. Its phenotypic expression should maintain good health and maintains production and reproductive efficiency. Strategies have to be evolved to promote the region-specific climate resilient breeding of cattle.

Final considerations

The large ruminants particularly the cattle play a significant role in meeting the future food demand. Therefore, it is very essential to ensure sustainable cattle production in the context of climate change. The climate change associated with heat stress plays a significant influential role in negatively influencing cattle production. The adverse impact of heat stress on milk, meat, and reproduction causes severe economic consequences in cattle enterprise. There are indigenous germplasms, which can overcome these adverse impacts of heat stress to maintain production. There are several adaptive mechanisms exhibited by the heat stressed cattle, which help them to survive in adverse environmental condition. However, it is a challenge to screen different indigenous breeds of cattle for their thermo-tolerance potential. It is very vital to choose breeds, which possess the ability to adapt to heat stress challenges without compromising production. Therefore, more research efforts are needed to breed cattle for climate resilience to identify more indigenous breeds which have the ability to survive in different agro-ecological zones. These efforts can sustain cattle production in the face-changing climate and it can ensure livestock-associated food security.

Conflict of interest

The authors declare no conflict of interest.

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