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Review Article

Climate Change and Cattle Production: Impact and Adaptation

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Abstract

Climate change has far-reaching consequences on several sectors of agriculture. Cattle production within animal agriculture is one of the most susceptible sectors for the devastating effects of climate change. Climate change associated heat stress negatively impacts cattle production both directly and indirectly. Heat stress reduces the feed intake which ultimately reduces the body weight, average daily gain and body condition scoring in cattle. Further, heat stress associated reduced feed intake also affects the milk production, meat production and reproduction in cattle. The high producing cattle are more vulnerable to heat stress than the low producing animals. Livestock exhibits a wide range of adaptive mechanisms to cope with environmental challenges. The classical adaptive mechanisms include morphological, behavioral, physiological, neuroendocrine, blood biochemical and cellular responses that act in coordination to promote the welfare and favour their survival in a specific environment. The detailed studies on these adaptive mechanisms have identified respiration rate, rectal temperature, Hb, PCV, cortisol, thyroid hormones to be reliable phenotypic markers and HSP70 as a confirmatory genotypic biomarker to assess the impact of heat stress in dairy cattle.

INTRODUCTION

Climate change is an unprecedented challenge faced by all the species on earth and this enduring effect hampers the balance of the ecosystem. Most of the developing countries would end up in severe poverty due to the devastating effects of the climate change on the agriculture and food production systems. Like other agricultural sectors, climate change also adversely impact the livestock sector. Among the livestock sector, cattle production is one of the most susceptible sectors for the devastating effects of climate change.

There are different climatic variables that influence the production aspects in livestock and among them, heat stress was considered the most detrimental factor which jeopardizes the cattle production [1]. The negative impacts of heat stress will become more severe in the future, as a consequence of ever progressing global warming and genetic selection for higher production continues. Moreover, even a minute increase in upper critical temperature may severely hamper the cattle production subjecting the farmers to be highly vulnerable to cope with the challenge Furthermore, The economic decline in the dairy industry is primarily associated with, lowered milk production, reduced reproduction, increased metabolic disorders and poor immune function warranting research efforts involving appropriate amelioration strategies to reverse the condition [2]. However, the animals themselves possess some of the inherent capabilities to withstand climate associated risks through the process of adaptation. This review is therefore, an attempt to collate and synthesis information pertaining to heat stress impact on cattle production. Efforts were also been made to highlight the significance of cattle adaptation pathways and different strategies to cope them to the adverse environmental condition.

Climate change and cattle production

Climate change negatively impacts cattle production both directly and indirectly. The direct effects comprise of rising temperature, variations in photoperiod as well as precipitation and, indirect effects include reduced feed quality as well as quantity, less water availability and higher disease susceptibility. Higher temperature along with humidity causes heat stress in cattle, which has a wide range of detrimental impacts such as reduced growth, lowered milk as well as meat production and impaired reproduction. Figure 1 describes the adverse impacts of climate change on various production aspects as well as the different adaptive mechanisms by which cattle counters heat stress.

Impact on growth

Growth is the increase in live body mass or cell multiplication which is controlled genetically and environmentally. Heat stress reduces the body weight, average daily gain and body condition scoring of animal [3]. The vulnerability of livestock to thermal stress decreases the dry matter intake that may negatively influence the growth performance of the animal [4]. In addition, it also decreases both the productive and reproductive performance of the heat stressed animal. According to NRCC, 2007 [5], the effect of heat stress on the crossbred was more than indigenous species. Increases in temperature to the tune of 2-6 °C associated with global warming negatively affect growth, puberty and maturity of animal apart from delaying the attainment of puberty [6]. Further, the animal exposed to chronic stress may undergo metabolic adaptation to cope with the stressful condition. Metabolic adaptation includes changes in the endocrine function, basal metabolism, metabolism of water and electrolytes, acid-base balance and alteration in rumen fermentation [6]. In addition to affecting the body weight, heat stress was also found to negatively influence the allometric measurements and body condition scoring [7]. Since circulating growth hormones characteristics appear to change very little during heat stress, and the hepatic growth hormones responsiveness was altered with increased temperature by measuring early signaling molecules in the growth hormone signal transduction cascade [8]. Hence, heat stress abatement practices such as shade, cooling and ventilation would assist in reducing the impact of heat stress on the animal [4].

Impact on milk production

One of the most significant factors affecting the milk production during heat stress is the unavailability of feed [9]. Environmental temperature above 35°C instigates stress response mechanisms in lactating dairy cows [10]. High producing dairy cows generates high metabolic heat than low producing animals. Therefore, high producing dairy cattle are more sensitive to heat stress [10]. Further, the increased metabolic heat production during heat stress reduces the milk production in livestock [1112]. Increasing air temperature, temperature-humidity index (THI) and rising rectal temperature above the critical threshold levels are related to decrease dry matter intake (DMI) and reduced milk yield [6]. Further, mechanisms preventing water loss are activated during heat stress so as to reduce the water loss through urine in favors of milk production [13]. In addition, the selective forage intake during heat stress with alternative rumen fermentation causes a decrease in acetate and alters the acetate: propionate ratio which causes reduction in milk fat yield [14]. The heat stressed animals exhibit shade seeking behavior, increased respiration rate (RR) and dilation of the blood vessels to reduce the effect on milk yield. During moderate and severe heat stress exposure, both saliva production and RR increases which were associated with a marked decline in milk production [15]. Further, the reduction in feed intake and increased water consumption along with increased body temperature declines the milk production performance of the dairy cattle. The maintenance energy requirement may increase by 20-30% in animals during heat stress [16]. This decreases the energy availability for productive functions mainly the milk production. This decrease in milk production can be transitory or long term depending on the length and severity of heat stress. If heat stress lowers milk production in early lactation dairy cows, potential milk production for the lactation will be decreased. Dairy animals drop 50% of milk production due to reduced feed intake and metabolic adaptation to heat stress and markedly changes post-absorptive nutrient metabolism [17].

The hot and humid climate affects the quantity and quality of milk. During the dry period, heat stress reduces mammary cell proliferation resulting in decreased milk production. Moreover, heat stress during the dry period negatively affects the function of the immune cell in lactating cows facing calving and also extended to the following lactation [18]. On comparing milk production during summer and spring in a dairy herd, it

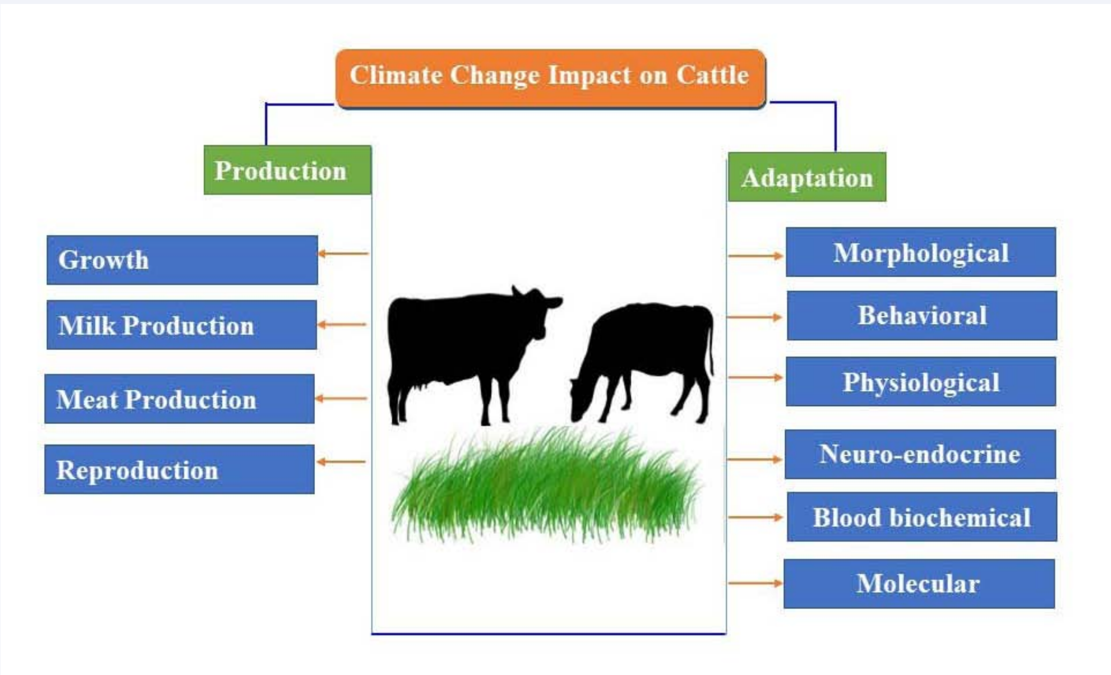

Figure 1 Impact of climate change on production and adaptation of cattle.

was found that lower milk yield (-10%), and also lower casein percentages were recorded in summer (2.18 vs. 2.58% and 72.4 vs. 77.7% respectively) [19]. Further, it was established that the fall in casein was due to the reduction in both α-casein and β-casein percentages. Additionally, only half of the loss in milk yield to thermal stress can be accounted for by a decrease in feed intake while the remaining loss could be due to altered carbohydrate and fat metabolism or direct effects on milk synthesis and secretion.

Impact on meat production

Climate change threatens both the meat quality as well as organoleptic characteristics [20]. The environmental factors determine the quality of meat during on farm, pre-slaughter and post-slaughter processing. In beef cattle, weight, thickness and colour of coat are the major determinants of meat production during heat stress condition [12]. These authors observed the impacts of heat stress on body weight, body size, carcass weight and fat thickness of animals. Pre and post slaughter environment has a greater influence on the tenderness of meat [21]. Another constraint of climate change in processing quality meat is the microbial attack. Microbial attacks are often on carcasses and meat especially when animals carry enteric pathogens in their gut.

Extreme heat stress results in the increased pH and darker meat colour [22]. These changes are due to the constant exposure of beef cattle to high ambient temperature until pre-slaughter. This result in adrenergic stress response is activated in which peripheral vasodilation and muscle glycogenolysis are induced as a result of the activity of adrenaline [23]. Hyperthermic condition and excessive exercise prior to slaughter results in tougher meat and this is attributed to the heat shortening effect. But in contrast, findings of Nardone et al. [7] reveal that high environmental temperature favours the marbling of muscle and also fat deposition in subcutaneous regions.

Impact on cattle reproduction

It has been reported that the ambient temperature associated infertility and reproductive problems in cattle has drawn the attention all over the world including tropics, subtropics and temperate regions [24,25]. The heat stress compromises the intrauterine environment by decreasing the blood flow towards the uterus and subsequently increasing the uterine temperature [26]. Several environmental factors play a crucial role in maintaining the reproductive functions of the dairy cow. Among these factors, heat stress was identified to be the critical cause of reduced fertility in dairy cattle [27]. It has also been emphasized that the thermal stress has a pertinent impact on the fetus and postpartum performance in Holstein heifer [28]. Further, studies reported that highly productive cattle are more susceptible to the changes in the environment which imparts alterations in the sexual cyclicity as well as the activity of ovaries [29].

Although the cattle are not directly exposed to heat stress, summer season related low fertility problems are the usual constraints faced by the farmers throughout the world [30]. This persisting effect of summer on fertility of cow results in altering the development of antral follicles during severe hot months [31]. Even minor changes in the core body temperature were established to be sensitive enough to induce changes in the estrous cyclicity in dairy cows [32]. The altered estrus cycle and behavior during exposure to heat stress results in the late manifestation of estrus and a lengthened estrus interval which leads to a high incidence of silent ovulation and anestrus in dairy cows [33]. The poor estrus expression during the heat stress usually reflects the reduced production level of gonadotropin releasing hormone (GnRH) as well as both the gonadotropins the follicle stimulating hormone (FSH) and leutinizing hormone (LH) in cows [34]. The altered LH secretion provides an ovarian environment wherein the dominant follicles grow in a low LH environment resulting in declined estradiol production which culminates in poor estrus expression reducing the fertility [35].

The effect of heat stress is prominent on the follicular development as the follicles require substantial time (40-50 days) to grow from immature follicles to antral follicles and consequently, the heat stress decreases the diameter of follicles and induces biochemical changes in the follicular fluid [36]. The higher ambient temperature reduces the possibilities of superovulation and also leads to a higher compromised embryonic development [37]. The heat stress compromised ovarian follicles leads to reduced production of blood inhibin which further reduces the FSH concentration in blood [35]. Moreover, the prolonged impact of heat stress (up to the final stage of follicular development) may culminate in the lower levels of androstenedione produced from thecal cells and a decline in the estradiol concentration in the follicular fluid [38]. Therefore, exposing the early follicular stages to heat stress may result in impaired pre-ovulatory follicular functions during the autumn season. Additionally, the conception rates were reported to decline during the summer season in comparison with winter months [39].

The embryo survival is threatened when the cattle are exposed to a constant heat stress. In addition, several reports described on the reduction of steroid concentration in the follicular fluid contained in the larger matured follicles especially during the summer season and it indicates a compromised aromatase activity [40,41,42]. This further leads to early embryonic loss and reduction in the rate of successful insemination [43]. Apart from the direct consequences of heat stress, the reproductive performances of dairy cattle are influenced indirectly through the reduced dry matter intake (DMI), nutrient utilization, estrus period and milk production. A substantial decline in dry matter intake results in low fertility during the postpartum period [44].

Adaptation of cattle to climate change

Livestock possesses a wide range of adaptive mechanisms to cope with environmental challenges. These include morphological, behavioral, physiological, neuroendocrine, blood biochemical and cellular responses that act in coordination to promote the welfare and favors them to survive in a specific environment [45]. Adaptive responses help the animals to maintain their internal milieu and help them to sustain their productivity under the prevailing climatic conditions.

Morphological adaptation

Animals evolve morphological characteristics according to the temperature prevailing in their agro-ecological zones. As per

Khalifa [46], morphological adaptation includes coat, fur depth, hair type, hair density, fat storage in hump or tail especially under desert conditions, skin colour and body size. In addition, Silanikove [47] also reported that during heat stress animals possess some of the morphological characteristics such as 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.

Dairy cattle from hot and arid conditions have light coloured hair coat with white, light red, red or a combination of these colours so as to protect the animal from the solar radiation [48]. Moreover, animals having light coloured coats absorb less heat compared to those having darker skin tone [49]. Further, smooth, light, short and thin hairs are seen in cows at arid conditions in order to enhance maximum heat dissipation during stress conditions [48]. For instance, black and white spots in Holstein Friesian cows make them adaptable to both cold and hot environment. The black skin absorbs more solar radiation while white reflects the radiation which helps them to maintain their body temperature [48]. For cattle to maintain their thermo-neutral zone they tend to dissipate heat through the sweat glands by the evaporative cooling mechanism. Therefore, by improving their sweat glands heat tolerance can be enhanced [50]. Further, there are several morphological adaptations that have evolved time immemorial in animals belonging to arid regions like short and thin hair, pigmented skin, short ears with tiny hair, movable and slender [51]. Hansen [52] observed that low metabolic rate lowered resistance to the flow of heat from the core to the periphery of the body. Consequently, the features of hair coat ensured heat dissipation and made Zebu cattle superior for heat tolerance. Research findings indicated that slick gene induced in the animal can regulate the body temperature affecting hair length [53,54]. Despite these, Dikmen et al. [54] conducted a study inducing slick hair gene to Holstein cows that rendered its carrier with a silk hair coat and improved their heat forbearance.

Behavioural adaptation

Changes in the environmental condition influence the performance and productivity of the animals. In an effort to adapt to varying environmental conditions, the animals exhibit several behavioural responses. The most important behavioural responses studied in dairy cattle include: shade seeking behaviour, standing time, feeding, defecating and urinating frequency, water intake, lying time, and increased frequency of drinking [55].

Shade seeing is a common behavioural response which helps the animals avoid exposing themselves to direct solar radiation. Generally, dairy farms comprise of shading structures that alleviate heat stress [56]. Studies have proved that cattle mostly preferred tree shades rather than shaded structures due to high evaporative cooling from tree leaves [57]. However, farmers widely go for shaded structures with light colour and iron material roofs [58]. When heat load increases, cows tend to reduce lying time and increase the standing time [59]. These activities increase their body surface area which promotes evaporative heat loss and also could circumvent radiative and convective heat from the ground [60]. However, a study conducted by Vijayakumar et al. [61] proved that sprinklers and fans in farms could effectively reduce the heat load thus increasing their lying time.

Generally, the defecation and urination frequency decreases as the heat load increases. This frequency relies mainly on the availability of feed, water and, environmental temperature [55]. Correspondingly, reports suggest that heat stressed cows showed a drastic decrease in urine frequency [62]. Cattle reduce the feed intake when exposed to extreme environmental conditions [63]. Feeding during the heat stress generally increases the metabolic heat increment in ruminants thus they tend to reduce their feed intake [16]. However, this may reduce both the body weight and body condition scoring which reflects the productive performance of cattle [64]. Water consumption increases during severe environmental conditions. Water is vital under heat stress condition and a cow usually prefers water with a moderate temperature that is neither too cold nor too hot [65]. Mostly, experts have recommended providing cold water during hot conditions or water below the body temperature which helps in maintaining body temperature.

Physiological Adaptation

Physiological adaption is another important adaptive mechanism exhibited by heat stressed cattle which helps to maintain homeostasis during exposure to adverse environmental condition [66]. The adaptability of the animal to heat stress was attained by altering the physiological responses such as respiration rate, rectal temperature, pulse rate, body temperature and sweating rate [67]. Further, the physiological modifications are needed to sustain the normal body temperature and to prevent hyperthermia [68]. Respiration rate is one of the primary physiological mechanism by which heat stressed cattle dissipate the body heat through respiratory evaporative cooling mechanisms [1]. During the exposure to hot environment, the animal increases the respiration rate to avoid the extra heat load in the body and thereby maintain homeothermy [67]. Higher respiration rate and sweating rate was observed in an animal exposed to high ambient temperature [69]. The increased rectal temperature in heat stressed animal is a natural mechanism for dissipating the additional heat load to maintain the thermal status of the livestock [70]. Further, the greater rectal temperature during summer also indicates the inability of the animals in maintaining the normal body temperature [45]. Increased pulse rate and rectal temperature were reported in farm animals during summer season [71,72]. Similarly, Katiyatiya et al. [73] also reported higher rectal temperature when animals were exposed to heat stress for six hours during daytime. The higher pulse rate enables the stressed animals to dissipate more heat to its surroundings by increasing the blood flow to their body surfaces [69]. Further, exposure of the animal to hot environment also increases the skin temperature. The increased skin temperature of the animal due to high ambient temperature alters the blood flow to the skin and redistributes the blood flow to the surface of the skin [74]. A study was conducted in both Nguni and Boran cattle breeds showed higher skin temperature during summer season [73]. Further, a comparative study in the indigenous zebu breeds (Gir, Sindhi, Indubrasil) showed higher magnitude for physiological parameters such as rectal temperature and heart rate during the afternoon (35.9^{0}C) [75].

Neuro-endocrine adaptation

Endocrine responses are one of the principal regulators of the animal adaptation. Both adrenal and thyroid glands have a significant role in thermoregulatory mechanism in the animal during stress [76]. The stress results to induce changes in the secretion of pituitary hormones, leading to altered metabolism, immune competence and behavior, as well as failures in reproduction [77]. The hormones associated with adaptation to heat stress include glucocorticoids, catecholamines, antidiuretic hormone (ADH), thyroid hormones, mineralocorticoids, growth hormone (GH) and prolactin (PRL), [78]. Minton [76] stated that environmental stressors have the potential to activate the hypothalamic-pituitary adrenocortical axis (HPA) and sympatho–adrenal medullary axis (SAM). When the animals are exposed to stress the body receives sensory information, the sympathetic nervous system sends the signal and activates adrenal medulla through acetylcholine. Finally, epinephrine and norepinephrine are released into the blood and act as a bodily mechanism for fight or flight response to overcome the stressful condition [79]. The HPA axis acts as another principal endocrine system involved in regulation of the stress response in livestock [80]. The HPA axis controls the enhanced production of glucocorticoids which act as the stress relieving hormone in heat stressed animals [80,81]. The animal exposed to acute stress results in high level of plasma cortisol production however, the level comes down during chronic stress [81]. Further, several studies clearly show the higher level of cortisol during heat stress and also identified as an indicator for heat stressed animal [82]. Increased production of cortisol also assists the stressed animals to meet the additional energy requirements for the adaptive mechanisms through the pathway of hepatic gluconeogenesis [83]. In addition, the increased glucocorticoid concentration indicates the severity of heat stress during exposure to hot environment. Aldosterone is a steroid hormone released from the cortex of the adrenal glands and involves in the regulation of water and mineral balance in the animal body [49]. During heat stress conditions the animals undergo severe dehydration and which results in the activation of the renin-angiotensin-aldosterone pathway to restore the water and electrolyte balance [84]. Several studies were conducted and reported the higher level of aldosterone in heat stressed livestock [84]. Further, thyroid hormones play an important role in regulating the thermogenesis and are identified as an indicator for assessing the thermo-tolerance of the farm animals. Significant reduction in concentration of triiodothyronine (T_3) and thyroxine (T_4) in plasma and in milk of lactating cows were reported and it is considered as another adaptive mechanism to avoid extra heat load as a result of increased metabolic activity [85]. The compromised pituitary thyroid axis activity was reported in steers with a reduction of approximately 40, 45.4 and 25.9% in TSH, T_4 and T_3 levels during heat stress reflecting their ability to produce less metabolic heat in an effort to adapt to heat stress exposure [86].

Blood biochemical response

The blood biochemical composition considerably reflects the health status of the cattle. There are several factors that determine the composition of blood and that especially include nutrition, management, stress and diseases [87]. Even moderate changes in the environmental condition bring significant variations in the blood biochemical composition. Since heat stress is the major effect of climate change, it has a large influence on the blood biochemical composition consisting of packed cell volume (PCV), hemoglobin (Hb), plasma glucose, albumin, total protein, total cholesterol, non esterified fatty acid (NEFA) in animals.

The heat stress in cattle leads to a significant decline in the red blood corpuscles (RBC) and Hb count and this decrease can be correlated to their adaptive capability [88]. The exposure of high temperature leads to high consumption of oxygen as a result of increased RR. This further increases the partial pressure of oxygen in blood reducing erythropoiesis and declined RBC and Hb values [89].

Similarly, it was emphasized that the heat stress related decline in PCV can be related to the excess requirement of water in the circulatory system in order to dissipate the heat through haemodilution effect [90].

On contrary to the trend of PCV and Hb, plasma albumin level in blood shows a positive trend (significant increase) during heat stress period in cattle [91]. In Holstein heifer, the plasma albumin concentration was found to be increased during the summer season in comparison with the winter season. This is attributed to the activity of plasma albumin as antioxidants to scavenge the free radicals during heat stress [92].

Additionally, Koubkova et al. [93], suggested that total protein increases significantly during heat stress and gradually reduces as a result of gluconeogenesis. Also, there are reports describing the relationship of increased total protein and albumin during the spring season. This could be due to the plenty feed availability during this period [94].

The glucose concentration in the serum has been derived from the process of gluconeogenesis. Therefore, summer season induced reduction in the glucose level could be due to the reduced gluconeogenesis [94]. However, Koubkova et al. [93], reported an increase in the glucose level during stress in cattle.

The metabolic activities are supported by the mobilization and utilization of non-esterified fatty acid (NEFA) during the testing condition [95]. The stress influences NEFA concentration that helps in determining the energy status of the animal [96]. The plasma level of NEFA decreases as a result of continuous exposure to heat stress in dairy cattle. This is due to the high requirement of NEFA in the liver and peripheral tissues as a source of energy [97]. Similar findings of reduced NEFA were reported by Baumgard and Rhoads [17] during heat stress in order to burn the glucose so as to reduce the metabolic heat production. Contrarily, Shehab-El-Deen et al. [36], opined that the NEFA production increases with the exposure in summer and this can be related to the adaptive capability of the cattle to maintain a constant energy throughout the summer season.

Further, the total serum cholesterol level shows considerable alterations during heat stress relative to normal condition. Ocak et al. [98], describes the total serum cholesterol to be reduced as an impact of thermal stress. Likewise, Alberghina et al. [94], also reported reduced total serum cholesterol in heat stressed dairy cows. Metabolic activities in stressed cows are controlled by the level of various enzymes in the blood. Findings of Mazzullo et al. [88], revealed that aspartate aminotransferase (AST) and alanine amino transferase (ALT) increases during the winter season in the cow. The alterations in the activity of these enzymes reflect the poor functioning of the liver. Similar results of ALT were established by Alameen and Abdelatif [99] in cross bred dairy cows. Hooda and Singh [100], reported decreased alkaline phosphatase (ALP) activity in buffaloe heifer during heat stress exposure.

Haptaglobin is an essential component in the lipid metabolic pathway. There are several contradictory findings pertaining to the haptaglobin concentration in heat stressed cows. The haptaglobin was established to be higher in heat stressed cows [94]. Similarly, Wenz et al. [101] also postulated the increasing trend of haptaglobin in dairy cows which is in par with the findings of Alberghina et al. [94]. In contrast, Chan et al. [102] reported no influence of heat stress on the haptaglobin concentration in dairy cows.

Cellular and molecular adaptation

The cellular level of adaptation is one of the acute systemic responses to heat stress and it plays a significant role in imparting thermo-tolerance to animals. Gene networks within and across the cells respond to a higher temperature through both intra- and extracellular signals that result in cellular adaptation. Further, when an animal subjected to single, severe but non-lethal heat exposure, the cellular thermo-tolerance develops and that facilitate the organism to endure the ensuing lethal heat stress. Cattles evolved in hot climates such as Senepol, Bostaurusindicus and Romosinuano had acquired different thermo-tolerant genes when exposed to a higher temperature [52]. Moreover, the cellular adaption of an animal achieved by the synthesis of heat shock proteins (HSPs) and other thermo-tolerant genes which are involved in anti-stress mechanisms during heat stress condition [103]. Cells reduce their DNA synthesis, transcription and translation process, alter the protein activity and increases HSPs production on exposure to heat stress [104]. Gene expression alters on exposure to heat stress and the classical example of activation of heat shock transcription factor 1 (HSF1) culminates in increased expression of HSPs, decreased expression of other proteins, increased glucose and amino acid oxidation, reduced fatty acid metabolism, activation of endocrine system of the stress response and activation of immune system [105]. The HSPs are molecular chaperones that help in protein folding, refolding and transportation. Further, they also prevent protein denaturation and aggregation during heat stress condition. When cells are exposed to high ambient temperatures the expression of many HSPs such as HSP32, HSP40, HSP60, HSP70, HSP90, and HSP110 were found to be increased [106]. In addition, the genes associated with HSP synthesis can be used as potential biomarkers for cattle adaptation under harsh environmental stresses [107]. Identification of the genes facilitating cellular thermo-tolerance may be helpful for developing heat tolerant cattle breeds through marker assisted selection breeding program.

The slick hair gene is responsible for producing a very short, sleek hair coat. Moreover, cattle with slick hair were observed to retain lower rectal temperatures (RTs) [54]. The impact of the slick hair gene on RT depended on the quantum of heat stress, age and lactation status of the animal. Approximately 0.18 to 0.4 decreased RT was observed for slick-haired crossbred calves in comparison with normal haired calves [108]. Natural resistance associated macrophage protein 1 (Nramp1) has been recognized as a major gene in many species. The Nramp1 gene is expressed in late endosomes coordinates the antimicrobial activity of macrophages. The genetic polymorphisms in the bovine HSP90AB1 and ATP1A1 genes were associated with heat tolerance in cattle. According to Littlejohn et al. [109], mutations in prolactin receptor genes (PRLR) offer additional thermo-tolerance to cattle other than its effects on short hair coat. In addition, the gene IGF-1 confers cellular resistance to heat stress in Nellore and Holstein cattle [110]. Muller et al. [111], established that the Fibroblast growth factors (FGFs) have important roles in cell repair in response to heat stress and it also protects the cells from injury. Furthermore, the interleukins (ILs) and toll-like receptors (TLRs) have a vital role in heat tolerance in Tharparkar cattle when they are exposed heat stress condition [112]. The NADH dehydrogenase, Tick resistance genes, Collagen, type IV, Kinesin family, Selenium binding protein, Annexin, glycosyltransferase, protein kinase C, transcription factor, thyroid hormone receptor, mitochondrial inositol protein, isocitrate dehydrogenase and butyrophilin, hosphofructo kinase are the additional genes associated with thermo-tolerance to warm climates in livestock [106].

CONCLUSION

This review highlighted the salient findings on the various impacts of climate change on cattle production. Climate change associated heat stress was identified to be the principal factor which adversely impacted all production aspects in cattle. Among the different categories of bovine, dairy cattle were found to be more sensitive for the temperature changes. Heat stress was established to reduce both the growth and milk production in dairy cattle. Further, heat stress also was found to have a profound influence on beef cattle production by altering both the quality and quantity of meat. In addition, all reproductive functions of cattle have been adversely affected by heat stress. All these adverse impacts have severe consequences on the economic return in cattle farms and this enormously affected the livelihood securities of poor and marginal cattle farmers. The second part of review addressed the various adaptive mechanisms exhibited by cattle to cope with heat stress challenges by maintaining homeostasis. The detailed studies on these adaptive mechanisms have identified respiration rate, rectal temperature, Hb, PCV, cortisol, thyroid hormones to be reliable phenotypic markers to quantify heat stress response in cattle. Further, HSP70 has been identified to be the confirmatory genotypic biomarker to assess the impact of heat stress in dairy cattle. However, breed differences were also established for the adaptive capabilities of cattle to heat stress challenges.

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