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Adaptation of Livestock to Environmental Challenges

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Abstract

Livestock undergoes various environmental challenges. Thermal stress is the most intriguing factor affecting livestock production in the ever changing climatic scenario. Adaptation is defined as the morphological, anatomical, physiological and biochemical characteristics of the animal which promote welfare and favor survival in specific environment. Environmental challenges negatively affect the growth, production and reproduction of livestock. Combined effect of temperature and humidity proved to be extremely fatal to the entire livestock population. Animal cope up with environmental challenges with various kinds of responses. These include physiological response, blood biochemical response, neuroendocrine response, molecular and cellular response, metabolic response and behavioral response. Physiological responses include alterations in body temperature, respiration rate, heart rate and skin temperature. Blood biochemical and endocrine responses are by which the animals try to cope up to adverse environmental conditions by altering the concentration of blood metabolites, stress and metabolic hormones under the control of nervous system. Cellular and molecular responses are the cardinal mechanisms by which the animal survives stress. Further, the animals try to adapt to the stress condition by altering their behavior. In addition, through evolutionary adaptive mechanisms animals developed few specialized structures and by which they avoid the influence of adverse environmental condition. All these responses play a major role in maintaining the homeostasis in livestock and make them survive in adverse environment. A deep understanding of these adaptive mechanisms are required, if one attempts to develop suitable ameliorative strategies to improve livestock production in changing climatic scenario.

Keywords: Adaptation; Respiration; Sweating; Behavior; Cortisol; Thyroid hormones; Heat shock protein

Introduction

Livestock undergo various kinds of stress which includes chemical, physical, nutritional, and thermal stress. Various factors affect livestock productivity which includes photoperiod, geographical location, age, breed, nutrient availability, water availability, management practices, and environmental conditions [1,2]. In the changing climatic scenario, thermal stress is the most crucial factor which hampers livestock productivity. Adaptation is the morphological, anatomical, physiological and biochemical characteristics of an animal which promote welfare and favor survival in a specific environment. Beyond thermo-neutral zone, animal has to use a portion of the metabolizable energy typically used for production to assure thermal balance. Combined effect of temperature and humidity will be extremely fatal to the livestock population across the globe [3]. This review is an attempt to collect information pertaining to these mechanisms which helps the livestock species to survive in a particular environment. Although the review targets addressing environmental stresses, special focus was given to highlight the impact of heat stress on the livestock production and its adaptation.

Environmental Stresses Affecting Livestock Production and Reproduction

Major environmental stresses affecting production and reproduction of livestock are heat and nutrition stress [4]. Increased ambient temperature leads to heat stress in livestock which has adverse effects on animal production and reproduction. Effects of heat stress in livestock are reduced feed intake, growth performance, milk yield, increased sweating rate, panting, rectal temperature, respiratory rate, and water intake [2]. Apart from these there are also changes in hematological parameters, electrolytes, metabolites, increased mortality and morbidity, and reduced immune function [5].

Growth is defined as the irreversible positive changes in the measured dimensions of the body. Body growth is affected by factors such as nutrients, hormones, enzymes and temperature. The evident effects of heat stress on growth performance are due to decrease in anabolic activity caused by decline in voluntary feed intake, and increase in tissue catabolism [6]. Further, heat stress causes reduction in the body condition score (BCS) due to negative energy balance. Factors such as, greater maintenance requirements during hot weather, poor appetite and low quality forages during summer months contributes to the slower growth and reduced body size [7].

Milk production appears to be particularly sensitive to the effects of heat stress. Heat stress significantly reduce milk protein, fat, somatic cell count (SCC) and solid not fat (SNF) in dairy cattle [8]. Particularly the effect of heat stress was more severe in high producing cows than the low producers. Reduced lactose content and milk yield as a result of heat stress may be attributed to the lower hepatic glucose synthesis as well as lower level of non esterified fatty acid (NEFA) in lactating animal. This ultimately causes reduced glucose supply to mammary gland to reduce milk yield [9]. Decline in nutrient absorption, effect on function of rumen and hormonal status and increased maintenance requirement which leads to decreased net energy supply for production are the other factors responsible for reduced milk production during heat stress [9-11].

Heat stress negatively affects reproduction in livestock. Increase in testicular temperature results in reduced sperm output, decreased sperm motility and increase in proportion of morphologically abnormal spermatozoa in the ejaculate [12]. Spermatocyte and spermatid are the cells that are most prone to damage during heat

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stress [12]. Further, heat stress also results in reduced fertility, libido and testicular degeneration.

Major components of the reproductive system have been found to be susceptible to heat stress in female animals. These include the estrus incidences, oocyte, granulosa and theca cells within the preovulatory follicle, developing embryo during early stages of development, corpus luteum and uterine endometrium. Under heat stress, estrous expression is reduced and increase in loss of embryo. Heat stress severely affects the oestrous behavior which ultimately leads to compromising the uterine environment in livestock [13]. In addition, heat stress also severely reduces the blood reproductive hormones, conception and calving rates.

Nutrition has a major role in the production performance of livestock. The lack of pasture availability due to environmental factors such as decline in rainfall and drought conditions will affect the nutrition requirements of animals. Nutritional stress affects reproduction, growth and milk production. Poor nutrition delays puberty reduces conception rate and increases pregnancy losses in cattle. [14]. Young animals are more sensitive to nutritional stress as the adaptive mechanisms will be poorly developed in the young animals [15]. During drought periods quantity and quality of forages decreases which further intensifies the nutritional stress impact on livestock production. In addition, the reduced quantity and quality of water for livestock as a result of climate change also severely impact both livestock production and reproduction. Considering the key role of the nutritional status on reproductive efficiency, nutritional and management strategies are essential for optimizing reproductive performance in livestock. Table 1 describes the different target organs for heat stress pathway and the corresponding responses of livestock to adapt to adverse environmental challenges

Genetic Control of Livestock Adaptation

Fitness and adaptation are influenced by genetic make-up and it determines an animal's tolerance to adverse conditions such as high temperature, drought, pests and diseases. Adaptation in terms of genetics is the heritable animal characteristics which favor survival of a population. Animal husbandry is being practicing in extreme environment conditions for centuries. Many breeds of the harsh environment have developed many adaptive traits that increase their survivability [16]. Natural selection results in the survival and successful reproduction of animals genetically adapted to a particular environment. The range unique adaptive characters of the indigenous livestock which evolved in stressful tropical environments enable them to survive and to be productive in adverse environments. Indian breeds of cattle like *Bos indicus* perform well in the hot climate as compared to exotic cattle *Bos taurus*, primarily due to their ability to survive in unfavorable environments. The inherent genetic variation is the major factor that determines adaptability as measured through survival and reproduction which interacts with constraints of environment and creating phenotypic variation [16]. Within species and between species competition for similar resources occurs which leads to phenotypic selections that allow survival of population [17]. Use of genetic tests like the Bovine SNP50 BeadChip may be used to identify genetic markers that predict thermo-tolerance [18]. Another approach for improving resistance to heat stress in dairy breeds is to introduce thermo-tolerant genes from other breeds like slick hair genes [18]. The slick hair gene has been introduced naturally into some Holstein cows in Puerto Rico and into a dairy breed in Venezuela called the Carora [19] indicating Slick Holsteins are better able to regulate body temperature during heat stress than cows with normal hair. Figure 1 describes the various adaptation strategies in livestock to maintain homeostasis during climatic stress condition.

Table 1: Different target organs for heat stress pathway and the corresponding responses of livestock to adapt to adverse environmental challenges. CRH-Corticotropin releasing hormone, GnRH-Gonadotropin releasing hormone, ACTH-Adrenocorticotropic hormone, LH-Lueitinising hormone, FSH-Follicular stimulating hormone, T3-Triiodothyronine, T4-Thyroxine, HSP-Heat shock protein, IGF-1-Insulin like growth factor-1'

Tissue	Response	Species	Reference
Hypothalamus	Increased secretion of CRH Decreased GnRH	Cattle and Buffalo	[72] [73]
Adrenal	Increased cortisol Increased aldosterone	Bovines Goat	[56] [74]
Pituitary	Increased ACTH secretion Increased Prolactin, Increased, Decreased or unchanged LH and FSH	Cattle Cattle	[20] [70] [72]
Thyroid	Decreased secretion of both T_3 and T_4	Goat Sheep	[24] [74] [55]
Cell	Increased expression of HSPs Increased expression of thermo-tolerant genes	Goats	[75]
Liver	Increased or unchanged IGF -1	Cattle	[76]

Physiological Mechanisms to Livestock Adaptation

Physiological mechanisms sets in gesture once animal were subjected to stress, which helps to maintain homeostasis and physical equilibrium within them [20]. Physiological responses can be classified into short term changes and long-term changes. Short-term changes are often caused by acute stressors, e.g. a heat wave while long-term changes may be due to chronic stressors. Acute stressors may also lead to permanent changes in gene expression pattern [21]. These changes can be used as a measure of dairy cow comfort and adaptability to a harsh environment or as a sensitive physiological measure of environmental modification [22]. Ribeiro et al. [23] reported that the adaptability in animals particularly in small ruminants was attained by altering the physiological parameters like rectal temperature, heart rate, and respiratory rate. Further, Gupta et al. [24] reported that body temperature is also a good measure of heat adaptation in animals and it represents the sum of all heat gain and heat loss processes of the body. In addition, Alam et al. [25] stated that these physiological modifications are essential to uphold the normal body temperature and to prevent hyperthermia. Hidalgo [26] reported that the animals adjust their internal body temperature by matching the amount of heat produced through metabolism with the heat flow from the animal to the adjacent environment. Heat flow occurs through processes dependent on ambient environmental temperature (sensible heat loss; i.e. conduction, convection, radiation) and humidity (latent heat loss; evaporation through sweating and panting). Several researches reported on the alterations in the physiological responses like respiration rate and rectal temperature [27], panting, drooling, reduced heart rates and profuse sweating, decreased feed intake [7], and reduced milk production being exhibited by cows, when they were placed beyond their comfort zone.

Respiratory rate

Gupta et al. [24] reported that the animals exhibited increased respiration rate under high ambient temperature. According to Renaudeau et al. [28] the first and foremost mechanism of an animal subjected to heat stress was increment in the respiration rate, causing

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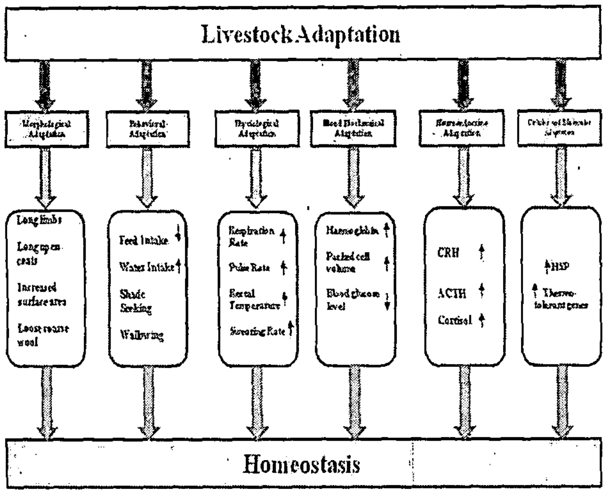

Figure 1: Various adaptation strategies in livestock to maintain homeostasis during climatic stress condition.

loss of heat through evaporation. Further, Ribeiro et al. [23] stated that during hot periods, animals use their respiratory mechanism to avoid increased rectal temperature, and thereby maintains homeothermy. The increase in skin temperature of heat stressed animals was due to the fact that the high ambient air temperature alters the blood flow and its redistribution thereby increasing the blood flow to the surfaces. Similar research finding was reported by Srikandakumar et al. [29] in Merino sheep.

Rectal temperature

Srikandakumar et al. [29] stated that rectal temperature was considered to be more sensitive indicator of body temperature in heat stressed animals. The rectal temperature is found to be increased when the animal is subjected to hot climate [30]. Similar findings were reported in sheep [31] and goat [32]. The increase in rectal temperature occurs, when the animal's body fails to maintain its heat balance [33]. Swenson and Reece [34] reported that the rectal temperature in goats varied from 38.3 to 40.0°C and has been frequently used as an indicator of the body temperature of the animals, although body temperature altered in different parts of the body throughout the day.

Pulse rate

Pulsation was reported to be increased by the effect of environmental temperature [24]. Alam et al. [25] reported that goats subjected under heat stress showed higher pulse rate compared to the control group. Further, Popoola [30] reported that the pulse rate increased with change in values of THI. Similar finding was observed in cow by Sivakumar et al. [35]. Marai et al. [31] reported that the increase in the pulse rate will increase blood flow from the core to the periphery of the body, resulting in higher heat loss by both sensible means (loss by conduction, convection and radiation) and insensible means (loss of water by diffusion through the skin).

Morphological Adaptation of Livestock

Livestock has been proved to adapt to a variety of environmental extremities [21]. The adaptation process can be classified into six categories such as anatomical, morphological, physiological, feeding behavior, metabolism, and performance [36,37]. According to Khalifa [1] the key morphological adaptation of the animal includes external insulation (coat and fur depth, hair type, hair density and subcutaneous fat), fat storage in hump or tail especially under desert conditions, skin colour and body size. Collier et al. [38] suggested that the main feature of an animal that affects the efficacy of evaporative heat loss from the skin surface was found to be sweat gland density, function and morphology, hair coat density, length colour and regulation of epidermal vascular supply. However, there are differences in thermoregulatory abilities among the breeds [39,40]. Further, Silanikove [41] observed some of the morphophysiological adaptations such as larger salivary glands, higher surface area of absorptive mucosa and the ability to increase considerable volume of the foregut when fed with high fibrous food.

Animals having light and sleek coats found to absorb less heat in comparison with those with dark colored and woolly coats. For a cattle maintained beyond the thermo neutral zone, evaporation is the solitary way of heat dissipation. Therefore, the possibility of developing heat tolerance in cattle lies in improving sweat gland function [42]. Short hair and thin hair, pigmented skin, short ears with tiny hair, movable and slender tail were found to be the morphological adaptations of *Bos taurus* cattle which resulted in enhanced heat loss [21]. Hansen [39] reported that the reduced metabolic rate, decreased resistance to flow of heat from the core to the periphery of the body and the salient features of the hair coat ensured the thermoregulatory mechanism to be superior in case of Zebu cattle. However, Ganaie et al. [22] added that buffaloes had poor heat tolerant capacity compared to other domestic ruminants and were susceptible to heat stress due to scarce and unevenly spread sweat glands, dark skin and sparse hair on their body surface.

According to Nay and Hayman [43] sweat glands were described as the potential source through which the heat is being dissipated. Johnson and Hales [44] added that the increase in blood flow to the sweat glands enables heat transfer to the skin and results in sweat production. Further, Finch [45] observed that sweating rates were found to be more in tropically adapted *Bos indicus* compared to temperate zone. This is because the transfer of metabolic heat to the skin occurs at a lower rate in *Bos taurus* than in *Bos indicus* cattle. Furthermore, study depicted that crossbred (*Bos taurus* × *Bos indicus*) cattle had larger and more sweat glands per unit area of the skin as well as greater sweat production than pure-bred *Bos taurus* [43]. Bernabucci et al. [11] concluded that skin colour is one of the factors that influence the adsorption of solar radiation. Further, Wang et al. [46] added that in Thai native cattle, the skin and skin constituents play significant roles in thermo-tolerance. Furthermore, Finch [47] reported skin capillaries and nerve fibres as the major element involved in characterising the sweating rate and thereby resulting in heat loss as well as heat load and heat storage.

Hidalgo [26] reported that the characteristics of the hair coat affects the heat transfer from the skin to the adjacent environment and thereby regulation of the body temperature. Further, Turnpenny et al. [48] and Gebremedhin et al. [49] reported that animals subjected to heat stress established an extreme temperature difference between the hair coat surface and the skin. Studies conducted in Florida [50] depicted that breeds of cattle with short, sleek hair coats possess higher thermo-tolerance than those of unadapted temperate breeds. Turnpenny et al. [48] reported coat depth to be an important factor and suggested that an increase in coat depth from 3 to 10 mm reduced the sensible heat loss in cattle by 17% at 20°C. da Silva, [51] reported that coat layer thickness was found to be greater for animals bred in temperate regions, more than 15 mm, while the same breed adapted

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to tropical climates present very thin coats, less than 8 mm deep. Further, Hidalgo [26] reported that hair density as another important feature of the hair coat. One specific gene identified to regulate body temperature during heat stress was found to be the slick hair gene affecting hair length [12,19].

Blood Biochemical Changes in Livestock Adaptation

Blood composition of animal are influenced by certain factors such as nutrition, management, sex, age, diseases and stress factors that might affect blood values [52]. The blood biochemical profiles are considered important in evaluating the health status of animals. Heat stress alters significantly the levels of Hb, PCV, plasma glucose, total protein and albumin in sheep [53]. The RBC and Hb count showed a significant decrease during warmest experimental periods in an experiment conducted by Mazzullo et al. [54]. Sejian et al. [55] reported that in ewes both Hb and PCV increased significantly on exposure to higher temperatures. High temperature increases oxygen consumption of the animals by increasing respiration rate. The higher oxygen consumption increases the partial pressure of oxygen in blood and decreases erythropoiesis, reducing the number of circulating erythrocytes and thus PCV and Hb values [24,35,56]. Gupta et al. [24] reported that the decline in PCV during the hot periods may be due to the more transport of water into the circulatory system for evaporative cooling or the haemodilution effect. Thermal stress apart from causing lower blood insulin also decreases tissue sensitivity to insulin thereby increases the insulin response [10,11]. A significant increase in the levels of plasma albumin was reported in cows [57] and buffalo calves [58] during heat stress. Prolonged exposure to solar radiation increased the concentration of plasma total protein, albumin, and globulin in goats and the reason for this is believed to be due to vasoconstriction and decreased plasma volume during heat stress [59]. They further added that Balady goats when subjected to short term heat stress for two days, the levels of total plasma protein, globulin and albumin was found to be decreased from 6.56, 4.04, 2.53, to 5.88, and 3.80, 2.08 g/dl respectively . The reason for this is attributed to the increase in plasma volume as a result of heat shock which causes decreased plasma protein concentration [24]. In a study conducted on Holstein cows by Koubkova et al. [58], it was found that during the hot period total protein values increased significantly from 68.95 to 76.75 g/l, then it gradually decreased, due to their rapid use for gluconeogenesis. They also reported an increase in the levels of urea and glucose significantly. In contrast Rashid et al. [60] observed no effect of thermal stress on blood urea in sheep. Thermal stress causes reduction in blood glucose and non esterified fatty acid (NEFA) level due to reduction in hepatic glucose synthesis [10].

Endocrine Responses of Livestock Adaptation

Endocrine responses are one of the principal regulators of animal adaptation. Moberg [61] reported that stress may result to inducing changes in the secretion of pituitary hormones, leading to altered metabolism, immune competence and behavior, as well as failures in reproduction. The hormones associated with the adaptation to heat stress are growth hormone (GH), prolactin (PRL), thyroid hormones, mineralocorticoids, glucocorticoids, catecholamines and antidiuretic hormone (ADH) [62]. Minton [63] stated that environmental stressors have the potential to activate the hypothalamo-pitutary-adrenal cortical axis (HPA) and sympatho–adrenal medullary axis. The activation of HPA during the heat stress leads to increased concentration of cortisol [36]. Acute exposure to high environmental temperatures leads to high level of plasma cortisol and decreased levels during the chronic phase [36]. In addition, during heat stress a significant reduction in concentrations of tri iodothyronine (T_3) and thyroxin (T_4) in plasma and in milk of lactating cows were reported [64]. This could be the adaptive mechanism to avoid extra heat load as a result of increased metabolic activity. However, according to Gupta et al. [24] during heat stress a significant increase in T_3 but not in T_4 level was observed in goat. However, contrasting results were also documented on plasma thyroid hormone levels in Australian cashmere goats [65] and cross bred sheep [66]. Heat stress affects the oestronesulphate in plasma of heat stressed animals and this was found to be the reason for reduced birth weights of the calves of Holstein cows [67]. They added that the concentration of progesterone in the plasma during heat stress was also found to be elevated in the cycling cows. Kumar et al. [68] documented that during short term exposure to high ambient temperature, the concentration of catecholamines and glucocorticoids were found to be elevated in goats. In bovines, during prolonged heat exposure plasma aldosterone level was reported to decline [68].

During summer months in cattle reduction of insulin like growth factor-1(IGF-1) was observed by Aggarwal and Upadhyay [69]. When THI exceeded 70, GH content in milk of low, medium and high production groups of cattle have declined [20]. The decreased level of GH leads to decline in calorigenesis, which aims for maintaining the body temperature [20]. When the temperature rose from 18 to 32°C, the level of prolactin (PRL) in Holstein heifers was found to be increased by more than 3 fold [70]. Similar findings were reported during heat stress in cow by Farooq et al. [20]. Even though the reason for the elevated levels of PRL are not clearly understood, Collier et al. [67]; Farooq et al. [20] attributed that the elevated PRL levels are involved in meeting increased water and electrolyte demands of heat stressed cows. Heat stress affects the reproduction by partly disrupting the release of gonadotrophin releasing hormones (GnRH) from hypothalamus and luteinising hormone (LH) and follicle stimulating hormone (FSH) from the anterior pituitary gland. Heat stress leads to reduced production of GnRH and also reduces the sensitivity of pituitary to GnRH [62]. Hansen [12] reported that severe heat stress can compromise LH secretion in males. He further emphasized that the major spermatogenic cell lineage in the testis is the disruption site for reproductive activity. According to Rensis and Scaramuzzi [71] heat stress reduces the degree of dominance of the selected follicle and this can be observed as reduced steroidogenic capacity of its theca and granulosa cells and a fall in blood estradiol concentrations. The level of plasma progesterone can be increased or decreased depending on the metabolic state of the animal and on whether the heat stress is acute or chronic. They further added that these endocrine alterations reduce the follicular activity and the ovulatory mechanism, which leads to a decrease in oocyte and embryo quality. Aggarwal and Upadhyay [69] also reported that during thermal stress, production and release of PGF 2α increases from the endometrium.

Cellular and Molecular Responses of Livestock Adaptation

The cellular heat stress response is one component of the acute systemic response to heat stress. Gene networks within and across cells and tissues respond to temperatures above the thermo-neutral zone with both intra- and extracellular signals that bring together cellular and whole-animal metabolism. Activation of these systems appears to be initiated at the skin surface temperatures exceeding

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35°C as the animals begins to rapidly increase evaporative heat loss mechanisms. Gene expression changes include 1) activation of heat shock transcription factor 1 (HSF1) 2) increased expression of heat shock proteins (HSP) and decreased expression and synthesis of other proteins 3) increased glucose and amino acid oxidation and reduced fatty acid metabolism 4) endocrine system activation of the stress response and 5) immune system activation via extracellular secretion of HSP [38]. General response of cells to heat stress includes: inhibition of DNA synthesis, transcription, RNA processing, translation, progression of cell cycle, disruption of cytoskeletal elements, protein denaturation and aggregation and changes in membrane permeability [72-77]. It is a well-established fact that the changes in gene expression are an integral part of the cellular response to thermal stress. Heat shock proteins (HSP) are activated by heat shock factors and their expression is increased when cells are exposed to high ambient temperatures. In recent studies, considerable differences in HSP70 expression between species and also at the level of different cell populations were reported [78]. Gupta et al. [24] reported that a change in gene expression occurs both during hyperthermia as well as hypothermia. Heat shock proteins play a crucial role in cell survival under heat stress and hence it is considered to be the confirmatory stress marker in livestock. During hypothermic stress the expression of many HSPs including HSP32, HSP40, HSP60, HSP70, HSP90, and HSP110 were found to be increased [24,79-81]. Patir and Upadhyay [79] also reported that the higher intensity and duration of thermal exposure cause higher expression of HSP70 in buffalo lymphocytes to maintain cellular homeostasis. However, immediate induction of HSP70 in the lymphocytes was found to be based on magnitude and time of thermal exposure. In goats Sharma et al. [81] reported that the expression of HSP 60, HSP 70 HSP 90 and Ubiquitin (UBQ) increased as a protective measure under heat stress. The mRNA expression of HSP60, HSP90 and UBQ were significantly higher during peak summer season as compared with peak winter season in both tropical and temperate region goats. HSP70 mRNA expression was significantly higher during summer season as compared with winter season in tropical region goats [80]. The result of the study conducted by Patir and Upadhyay [79] indicates that thermal exposure leads to the induction of HSP70 and decline in the immune status of buffalo heifers.

Conclusion

Environmental factors are the primary factors influencing livestock production in the changing climatic condition. Environmental stresses reduce production parameters like growth, milk yield, and reproduction in livestock leading to severe economic constraints. Livestock possess a wide range of adaptive mechanisms such as physiological, morphological, biochemical, endocrine, cellular and molecular responses to cope up with environmental challenges. However, while doing so their productive potential is compromised. To reduce the economic burden on farmers as a result of environmental stresses, strategies need to be developed with multidisciplinary approach to reduce the adverse effects of environmental stresses negatively impacting livestock production. Efforts are equally needed to further understand the hidden intricacies of molecular, cellular and other mechanisms of livestock adaptation as this might pave way for developing suitable amelioration strategies.

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