Adaptive Mechanisms of Livestock to Changing Climate

9

V.P. Maurya, Veerasamy Sejian, Mahesh Gupta, S.S. Dangi, Ankita Kushwaha, Gyanendra Singh, and Mihir Sarkar

Abstract

In the current scenario, climate change is occurring all over the world, which directly or indirectly affecting the agricultural production as well as the production of livestock. The arid and semiarid region of the world, where more than 75 % population of livestock exists, will be going to have pronounced effect of climatic change. Amongst the other stresses, heat stress is the most vital climatic stress which drastically affects the productive potential of livestock, and sometimes it is lethal to animal survival in harsh conditions. High ambient temperature, air movement, solar radiation, wind speed and relative humidity are important attributes of the climatic variables. Amongst the above-mentioned variables, high temperature, radiation and humidity are the most important factors, which drastically affect the overall performance of livestock with substantial reduction in meat, milk and egg production. In this context, the chapter highlights the significance of studying the impact of multiple stresses impacting livestock production simultaneously. The different adaptive means by which livestock respond to fluctuation of climatic changes are physiological, blood-biochemical, neuroendocrine, cellular and molecular mechanisms, respectively. In present climate change scenario, several mitigation strategies are to be implemented by which the production of livestock may be sustained to an extent even in harsh climatic conditions.

Keywords

Climate change • Livestock • Mitigation • Mortality • Productive potential

V.P. Maurya (✉) • M. Gupta • S.S. Dangi
A. Kushwaha • G. Singh • M. Sarkar
Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh 243122, India
e-mail: vijaipmaurya@gmail.com

V. Sejian
Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*, DOI 10.1007/978-81-322-2265-1_9, © Springer India 2015

9.1 Introduction

The impact of climatic change on natural resources and livestock is very vital and is being realised all over the world. In a developing country like India, more than 70 % percent population depends on agriculture and livestock, and these together provide sustainability and stability to national economy in the form of food security and farm energy (Singh et al. 2011). Environmental factors such as ambient temperature, solar radiation and humidity have direct and indirect effects on animals and affects worldwide livestock production (Nienaber et al. 1999). Under present climate conditions, in many areas of the world, animals are suffering from heat stress because they lack the ability to dissipate the environmental heat, which results decrease in milk production and reproduction in dairy cows (Fuquay 1981). Under climate change conditions, these responses could be enhanced and even extended to other areas around the world. The hot climate impairs productive and reproductive efficiency, and metabolic and immune response of animals which finally affects the health of livestock. It is evident from the Intergovernmental Panel on Climate Change that the poorest are the most vulnerable people and thus will be the worst affected.

The prominent relation between climatic variables and neuroendocrine system used to change the behaviour of livestock residing in that particular area (Baumgard et al. 2012). It is still not clear how heat stress affects the post-absorptive metabolism and nutrient partitioning/utilisation through hyperthermia's and/ or endocrine system (Collier et al. 2005). Livestock production will be affected by changes in temperature and water availability through impacts on pasture and forage crop quantity and quality, feed-grain production and price and disease and pest distributions. In Indian subcontinent, heat stress is the most important climatic stress which adversely affects the livestock and sometimes even affects their survival (Sejian et al. 2012a). During harsh climate, generally animals cover long distances in the search of feed and water, and sometimes because of long-distance walking, they have negative energy balance (Maurya et al. 2012; Sejian et al. 2012b). In current impending climatic changes, animals experience stress and to maintain homeothermy require extra energy for different productive processes. Along with the large ruminants, small ruminants are also critical to the development of sustainable and environmentally sound production systems (Ben Salem and Smith 2008). The sheep and goats are generally reared in arid and semiarid region of the world and are very important for the socioeconomic uplift of people dependent on these animals. Due to the climate change, the animals are being exposed to feed scarcity and elevated ambient temperature which negatively affect the production and reproductive traits of animals (Maurya et al. 2004; Marai et al. 2007).

Thermal stress affects the physiological and behavioural responses of animals which vary in intensity and duration in relation to the animal's genetic make-up and environmental factors in coordination with the behavioural, endocrinological, cardiorespiratory and immune system. In totality, the climate change has a negative impact in the long run, and it may reduce animal production and profitability by lowering feed efficiency, milk production and reproductive rate (St Pierre et al. 2003). In the face of climate challenges, adaptation of different livestock species to tropical conditions becomes highly imperative. A multifaceted approach is urgently needed to study the animal's ability to survive in harsh environments. The adaptation in the different physiological responses, biochemical status and composition and hormonal changes will be there to help animals to survive and produce in such prevailing climatic conditions. The present book chapter will have an insight about the different adaptive mechanism adopted by livestock to maintain their *internal milieu* and sustain productivity.

9.2 Physiological Responses and Adaptability

All animals thrive well in their thermoneutral zone, and whenever they are exposed outside to their respective zone, some portion of their metabolisable energy is diverted to maintain their thermal balance. The animal tries to maintain a relatively stable body temperature by behavioural and physiological means (Bucklin et al. 1992). High ambient temperature, relative humidity and radiant energy compromise the ability of animals to dissipate heat due to which the body temperature of animals increases. To maintain the body temperature within physiological limit, animals initiate compensatory and adaptive mechanisms to re-establish homeothermy and homeostasis, which is important for the survival of the animal. The relative change in the various physiological responses like respiration rate, pulse rate and rectal temperature gives an indication of stress imposed on livestock. The ability of an animal to withstand the rigours of climatic stress under warm conditions has been assessed physiologically by means of changes in body temperature, respiration rate and pulse rate (Sethi et al. 1994). By assessing the change in the physiological responses, the adaptability of a particular livestock may be studied, and environmental modification may be made to provide some comfort to the livestock.

The respiration rate is considered to be a reliable index under tropical condition and provides the information about the capability and adaptability of animals to that particular environment in which animals are being reared, and it also gives an indication about the discomfort of the animal. The increase in respiration rate is supposed to be the first action to mitigate the effect of heat stress. The onset of sweating is the next rapid reaction of animals to heat exposure and increases linearly with the increase in ambient temperature (Kamal 1975). Animals exposed to hot environment manifest a significant increase in physiological responses and reduction in productive potential. Animals which can maintain their physiological responses within normal limits under stressful environmental condition may be considered adapted to that environment and, hence, may be worth rearing commercially. In comparison to pulse rate, the respiration rate and rectal temperature appear to be more sensitive indicators of heat stress (Lemerle and Goddard 1986). The respiration is affected most with solar radiation and other related environmental variables.

The ambient temperature has significant relation with the fluctuation in the pulse rate (Raizada et al. 1980); however during morning hours, the pulse rate starts with the lower side, and during afternoon, it increases because of circadian rhythm (Maurya et al. 2007; Sejian et al. 2010b). The status of rectal temperature provides a useful and important indication about the heat storage in the animal's body, and higher rectal temperature of the animals drastically affects the allometric measurements, reproduction and lactation efficiency of the livestock (Hansen and Arechiga 1999). The value of rectal temperature also gives an idea about the adaptability of livestock to the particular environment. Even a rise of less than 1 °C in rectal temperature is enough to reduce performance in most livestock species (Lefcourt et al. 1986). RT is generally considered to be a useful measure of body temperature, and changes in RT indicate changes of a similar magnitude in deep body temperature (Maurya et al. 2007). Change in rectal temperature has been considered an indicator of heat storage in an animal's body and may be used to assess the adversity of thermal environment, which can affect growth, lactation and reproduction of dairy animals. The rectal temperature is recognised as an important measure of physiological status as well as an ideal indicator for the assessment of stress in animals (Maurya et al. 2010; Sejian et al. 2012a). During heat stress, high rectal temperature of livestock indicates that their homeothermic status is disturbed. Under such situation, the animals cannot effectively counter heat stress by enhancing heat loss through their physical and physiological process (Joshi and Tripathy 1991).

9.3 Multiple Stresses and Adaptability

In the tropics, grazing animals are exposed to less feed availability and low quality of vegetation. So the animals attempt to adapt to these adverse conditions by increasing the time for which they graze each day and also by dispersing more widely (Sejian et al. 2012c). In some areas, animals walk long distance in search of food and they are exposed to negative energy balance, and their physiological responses, endocrine and enzymes' release status and productivity in animals (Maurya et al. 2012; Sejian et al. 2012c) also alter. In addition to solar radiation, high humidity, severe drought, thermal, nutritional and walking are the major stresses that sheep and goats are exposed to (Sejian et al. 2012c, d). The animals try to adapt theirself to higher temperatures on prolonged exposure, but production losses will occur in response to higher-temperature events which lead to depressed voluntary feed intake, reduced weight gain and lower reproduction during summer. As a result of changing climatic conditions, multiple stresses have become a common occurrence in semiarid tropical environment. When animals are exposed to multiple stresses, the animal starts to use their body reserve to sustain their vital functions of the body, but their body reserves are not sufficient to effectively counter such environmental extremes (Sejian et al. 2010b). As a result, their adaptive capability is hampered and their homeothermy is badly compromised. The climatic stress also affects the body condition score of the animals. The type of nutrition consumed and body condition scoring (BCS) also seem to affect the respiration rate under heat stress conditions (Sejian et al. 2010a). The body condition score also affects the reproductive efficiency and productive performance of animals (Maurya et al. 2009).

The heat stress increases the blood circulation in the periphery of the animal's body to facilitate the heat loss via conduction and convection (Choshniak et al. 1982). Cattle change posture and orientation to the sun to reduce gain of heat from solar radiation. Moreover, chronic exposure to elevated environmental temperatures results in a lightening of the hair coat. Heat stress also leads to activation of evaporative heat loss mechanisms involving an increase in sweating rate and respiratory minute volume. About 70–85 % of maximal heat loss via evaporation is due to sweating with the remainder due to respiration. As air temperatures approach those of skin temperature, evaporation becomes the major route for heat exchange with the environment. There are reports which suggest that during thermal stress, both Hb and PCV decreased significantly (Naqvi 1987; Maurya et al. 2007). This could be attributed to haemodilution effect where more water is transported in the circulatory system for evaporative cooling and increase in the blood volume of these animals. In addition, Marai et al. (2007) reported red cell destruction as a reason for reduced Hb and PCV in thermal-stressed animals. A negative correlation between plasma protein and elevated environmental temperature has been reported in some studies (Sejian et al. 2010b).

The selection of animals which are tolerant to environmental stress results in reduced productivity, and such animals take a long time to reach maturity and a low level of milk production. So in such condition, by altering the environment, production may be increased by faster pace. The climate change and thermal stress affect physiological responses and productive and reproductive potential of animals (Collier et al. 2012). It is the prime importance to understand the complex physiological responses related to other mechanisms of the livestock body.

9.4 Temperature–Humidity Index

The dairy animals of tropical regions are subjected to high ambient temperatures (Ta), relative humidity (RH) and solar radiation for most of the period of a year. In the condition of heat stress, the physiological ability of the animals is being compromised and animals are not able to dissipate heat. There should be some ways and means by which a dairy man is able to assess the level of heat stress on the animals. The Temperature–Humidity Index (THI) is one of the best assessment tools by which we can know the impact of heat stress on producing animals widely used in hot areas all over the world to assess the impact of heat stress on dairy cows. According to Du Preez et al. (1990), milk production is not affected by heat stress when mean THI values are between 35 and 72. However, milk production and feed intake begin to decline when THI reaches 72 and continue to decline sharply at a THI value of 76 or greater. Milk yield decreases of 10–40 % have been reported for Holstein cows during the summer as compared to the winter (Du Preez et al. 1990). The THI is generally at higher side when the high ambient temperature is coupled with more relative humidity (West et al. 1999). It has been widely published in the literature that lactating cows do not experience stress when THI is less than 72 and severe stress when THI exceeds 88. Zimbelman et al. (2007) reported that the THI has very close relation with air movement, solar radiation and above all the milk yield. He found that dairy cows producing more than 35 kg/day of milk need additional cooling when average THI is 68 for more than 17 h/day.

9.5 Metabolic and Hormonal Response to Adaptability

The animals exposed to heat stress reduce feed intake and increase water intake, and in addition to this, the endocrine status of the animal also changes which in turn increases the maintenance requirement (Collier et al. 2005) and drastically affects the production in animals (Rhoads et al. 2009). During prolonged heat stress, the homeostatic responses of animals change in relation to acclimation to a particular environment, and the target tissue responsiveness to the environmental stimuli also alters (Horowitz 2002). The concentration of T_4, T_3, prolactin, GH, mineralocorticoids and glucocorticoids gets affected, and the endogenous heat production is controlled in coordination of the above hormones (Collier et al. 2005). Circulating prolactin levels are increased during thermal stress in a variety of mammals including ruminants (Roy and Prakash 2007). This is paradoxical as reduced nutrient intake in thermoneutral ruminants, decreases circulating prolactin concentrations (Bocquier et al. 1998). A direct (independent of reduced feed intake) effect of heat stress on serum prolactin levels has been shown (Ronchi et al. 2001). The prolactin generally helps in maintaining galactopoiesis and lactogenesis in ruminants, but it may play an important role in helping insensible heat loss and sweat gland function (Beede and Collier 1986).

The thermal stress affects the functioning of hypothalamic–pituitary–adrenal axis (Collier et al. 2005). Corticotropin-releasing hormone stimulates somatostatin, possibly a key mechanism by which heat-stressed animals have reduced GH and thyroid levels (Riedel et al. 1998). In heat-stressed cows, there is an increase in the basal level of insulin despite marked reductions in nutrient intake (Yarney et al. 1990). The increase in basal insulin levels appears due to increase pancreas' secretion. Adrenal corticoids, mainly cortisol, elicit physiological adjustments which enable animals to tolerate stressful conditions (Naqvi and Hooda 1991). During heat stress, plasma cortisol level increases which also enhances glucose formation in heat-stressed animals. The glucocorticoids also work as vasodilators to help heat loss and have stimulatory effect on proteolysis and lipolysis mechanism, which provide energy to the animal during such harsh climatic situations (Cunningham and Klein 2007). Heat stress decreases insulin level in the blood (Haque et al. 2012) due to decrease in heat production. In addition to this heat stress, increases in lipolysis activity in animals also elevate blood nonesterified free fatty acid (NEFA) levels and reduce insulin sensitivity and thus decrease muscle glucose uptake.

The T_3 and T_4 are the calorigenic hormones which fluctuate different cellular processes in the body. The animals exposed to thermal stress have reduced level of T_3 and T_4, and this reduced level of T_3 and T_4 might be an adaptive mechanism followed by animals to reduce metabolic rate and heat production (Sejian et al. 2010b). The thyroid hormone plays a crucial role in the productive efficiency of animals and may be considered as index for the metabolic status of animals (Todini et al. 2007). Uetake et al. (2006) reported that NEFA concentration in the blood is influenced by stress, and it is frequently used to assess the energy status of animals (Macrae et al. 2006). During stress, animals fulfil its metabolic fuel requirement due to mobilisation of NEFA (Cunningham and Klein 2007). The reduction in insulin action during heat stress also allows for adipose lipolysis and mobilisation of nonesterified fatty acids. Post-absorptive carbohydrate metabolism is also altered by the reduced insulin action with the net effect of reduced glucose uptake by systemic tissues (i.e. muscle and adipose). The reduced nutrient uptake and the net release of nutrients (i.e. amino acids and NEFA) by systemic tissues are key homeorhetic (an acclimated response vs. an acute/homeostatic response) mechanisms implemented by heat-stressed animals (Bauman and Currie 1980).

9.6 Cellular Response, Heat Stress and the Adaptability

The heat stress affects the productive performance of the animals which is being reflected in the homeokinetic changes in the animals which is considered to be an effort made by animal to regulate its temperature. The animals thriving in the hot climate have acquired some genes that protect cells from the increased environmental temperatures. Paula-Lopes et al. (2003) reported that lymphocytes from Brahman and Senepol cows were more resistant to heat-induced apoptosis than lymphocytes from Angus and Holstein cows. The heat stress increases the oxidative stress in the body of an animal, and because of that, there is an enhanced production of free radicals in the body and this free radical decreases the antioxidant defence system (Trevisan et al. 2001). The damage made by free radicals during thermal stress may be minimised by the use of vitamin C, vitamin E and β-carotene as they act as vital antioxidant. Besides these, different metalloenzymes, viz. glutathione peroxidase (Se), catalase (Fe) and superoxide dismutase (Cu, Zn and Mn), are very crucial in protecting the internal cells from oxidative damage. The major defences in detoxification of superoxide anion and hydrogen peroxide are superoxide dismutase (SOD), catalase and glutathione peroxidase (Chance et al. 1979). SOD is now known to catalyse the dismutation of superoxide to hydrogen peroxide and oxygen. Bernabucci et al. (2002) reported an increase in superoxide dismutase (SOD) and glutathione peroxidase (GPX) concentration in prepartum cows when animals were exposed to higher ambient temperature. In addition to this, Chandra and Aggarwal (2009) also reported a higher level of SOD in prepartum crossbred cows during summer. During heat stress, there is increased production of hydrogen peroxide (H_2O_2) due to increased activity of SOD and GPX. GPX is a selenium-dependent antioxidant enzyme. It converts H_2O_2 to water. The increased production of H_2O_2 due to increased activity of SOD during heat stress results in a coordinated increase in GPX.

Catalase is a haem-containing enzyme that catalyses the dismutation of hydrogen peroxide into water and oxygen. Catalase takes care of the cytosolic and mitochondrial peroxides formed during urate oxidation. Mitochondrial SOD readily converts the bulk of mitochondrial superoxide ions to H_2O_2. Thus, SOD and catalase protect the cell from the damage due to the secondary generation of highly reactive hydroxyl group from superoxide ion to H_2O_2. Kumar (2005) observed a significant positive correlation of THI with the erythrocyte catalase activity in Murrah buffalo and KF cattle. Chandra and Aggarwal (2009) also reported higher catalase activity in prepartum crossbred cows during summer.

Lipid peroxidation is commonly measured in terms of thiobarbituric acid-reactive substance (TBARS). Erythrocytes, which are rich in polyunsaturated fatty acids (PUFA), on being exposed to high concentration of oxygen, are highly susceptible to peroxidation damage (Clemens and Waller 1987). The thermal stress increases the oxidative stress in the cell, and this leads to the increase of TBARS in the animals' blood which leads to increased erythrocyte membrane fragility

(Bernabucci et al. 2002). More et al. (1980) reported a significant increase in the serum protein of sheep exposed to heat stress. The increase in serum protein could be a physiological attempt to maintain extended plasma volume. In contrast to the above finding, Verma et al. (2000) observed a significant decrease in protein concentration during summer season in a lactating cow and buffalo. The level of plasma albumin plays a vital role in the scavenging activity to remove free radical from the system, that's why albumin works as an antioxidant during thermal stress (Koubkova et al. 2002).

Although there is a good amount of knowledge about the physiological aspects, the effects of heat stress at the cellular and genetic level are still being unrevealed (Collier et al. 2006). Functional genomics research is providing new knowledge about the impact of heat stress on livestock production and reproduction. Using functional genomics to identify genes that are up- or down-regulated during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and towards the creation of therapeutic drugs and treatments that target affected genes (Collier et al. 2012). Identification of SNPs that are associated with variation in animal resistance or sensitivity to thermal stress will permit screening of the presence or absence of desirable or undesirable alleles of animals (Hayes et al. 2009). Another potential route of information flow from the surface to the whole system would be via secreted heat shock proteins (HSPs) released from the skin epithelium during heat stress which would act as an alarm system to assist in mobilising the acute response to thermal shock (Collier et al. 2012). Activation of the heat shock response in cells in many cases leads to secretions of HSPs into the extracellular space and plasma (Ireland et al. 2007). It has been hypothesised that secreted heat shock protein acts as an alarm signal for the immune system and several measures of innate immunity are increased following increases in secreted HSPs in blood (Fleshner and Johnson 2005). Secreted HSPs have also been shown to improve survival of neural cells subjected to environmental and metabolic stressors (Tytell 2005).

9.7 Female Reproduction, Heat Stress and Adaptability

The heat stress drastically affects animals' reproductive efficiency by delaying conception rate of the animals after calving. It may delay rebreeding and decrease the number of cows regularly coming in heat and subsequently decrease the number of inseminated cows that settle as pregnant (Hansen 1994). The heat stress also affects the quality of developing preovulatory follicle by fluctuating the oestrogen and progesterone ratios which in turn affect the intensity of sexual behaviour, oviduct and uterus microenvironment and finally development of embryo. Several research findings show that heat stress compromises the quality of developing oocyte and of the follicle. High air temperatures 10 days before oestrus were associated with low fertility (Al-Katanani et al. 2002). Steroid production by cultured granulosa and thecal cells was low when cells were obtained from cows exposed to heat stress 20–26 days previously (Roth et al. 2001). In goats, heat stress reduced plasma concentrations of oestradiol and lowered follicular oestradiol concentration, aromatase activity and luteinising hormone (LH) receptor level and delayed ovulation (Ozawa et al. 2005). Cultured follicular cells experience reduced steroid production at elevated temperature in cattle (Bridges et al. 2005). The oocyte maturation is disrupted at elevated temperature (Wang et al. 2009). It has been reported by Roth et al. (2000) that lactating dairy cows exposed to heat stress had increased numbers of small and medium follicles.

The heat stress drastically affects preimplantation of embryo at early stage, but the susceptibility declines as development proceeds. It is an established fact that reproduction processes are influenced during thermal exposure (Naqvi et al. 2004; Sejian et al. 2010c) and glucocorticoids are paramount in mediating the inhibitory effects of stress on reproduction. Thermal stress influence on sexual behaviour (Maurya et al. 2005), fertility (Maurya et al. 2011), embryo quality and production is a well-established fact (Naqvi et al. 2004). The birth weights of lambs of heat-stressed ewes are generally lower. This could be attributed to the fact that heat stress may cause a temporal impairment of placental size and function, resulting in a transient reduction in foetal growth rate. In cattle, for example, Ealy et al. (1993) found that exposure of lactating cows to heat stress, when embryos were 1–2 cells, reduced the proportion of embryos that developed to the blastocyst stage at day 8 after oestrus. However, heat stress at days 3 (8–16 cells), 5 (morula) and 7 (blastocysts) had no effect on the proportion of embryos that were blastocysts at day 8. In cows, the adverse effects of heat shock on cultured embryos also are reduced as they become more advanced in development (Sakatani et al. 2004). It has been reported by Matsuzuka et al. (2005) that maternal heat stress resulted in increased reactive oxygen species activity in oviducts and embryos and reduced glutathione content in recovered embryos. Pérez-Crespo et al. (2005) found that female embryos are better able to survive effects of elevated temperature than male mice and this gender difference has been demonstrated to be caused by reduced reactive oxygen species production in females. As embryo development advances, it acquires capacity synthesis of heat shock protein 70 (HSP70), which stabilises intracellular proteins and organelles and inhibits apoptosis (Brodsky and Chiosis 2006).

The animal exposed to thermal stress during the early stage of pregnancy has reduced foetal growth, placental weight and placental hormone level. The effect of heat stress is more pronounced on the developing foetus during mid-gestation as compared to advance gestation (Wallace et al. 2005). During heat stress, the placental function also affects due to redistribution of blood to the periphery and reduced perfusion of the placental vascular bed (Alexander et al. 1987) and reduces the foetal weight in sheep (Wallace et al. (2005)). Similar effects of maternal heat stress on placental function and foetal development occur in cows. It is an well-accepted fact that stress during foetal stage can result in changes in physiological function during adult stage.

9.8 Male Reproduction, Heat Stress and Adaptability

Thermal stress drastically affects each of sexual activity, endocrine and testis functions, spermatogenesis and physical and chemical characteristics of the semen (Abdel Samee et al. 1997). Thermal stress decreases the ability of the male for fertile mating. Seminal plasma provides the suitable medium for spermatozoa which is a mixture of secretions that come from the male accessory reproductive organs. The biochemical constituents of seminal plasma also play a vital role for the well-being of spermatozoa and also act as vehicle for sperms (Mann and Lutwak mann 1981). Testosterone plays an important role in initiation of the sex drive and optimal functioning of the testis (McDonald and Pineda 1989). Physiological concentrations of testosterone are responsible to induce both behavioural and physical changes necessary for exhibiting libido, secreting pre-seminal fluid, protrusion of penis and complete erection. Testosterone is the hormone responsible for spermatogenesis and sexual behaviour. During thermal stress, reduction in testosterone secretion limits the male reproductive efficiency. Higher body or ambient temperature decreases sperm count as well as circulating testosterone levels in blood (Murray 1997).

The testes of the animals are suspended in the scrotum outside the body, and the temperature of the scrotum is slightly less than the general body temperature. A complex thermoregulatory system present in the testis exchanges heat by counter-current mechanism known as pampiniform plexus. The scrotum also has a unique muscle known as tunica dartos muscle which regulates scrotal surface area, and the position of the scrotum relative to the body is performed by the cremaster muscle. The tunica dartos muscle can be used as an index (TDI) to measure the ability of the male to tolerate increased ambient temperatures, as it reflects the magnitude of vascular heat exchange. During high ambient temperatures, the tunica dartos muscle extends to dissipate as much of the excess heat as possible from the testes. In rams, Marai et al. (2006) used tunica dartos indices (TDI) to measure the ability of the male to tolerate increased ambient temperatures. It is interpreted as the distance between the testes and the abdominal wall. This muscle thus defines the magnitude of vascular heat exchange.

The testis is located outside the body, and thermal stress has a direct effect on it leading to reduced semen quality in the form of reduced sperm output, decreased sperm motility and an increased acrosomal damage and proportion of morphologically abnormal spermatozoa in the ejaculate. The spermatocytes and spermatids are most susceptible to damage by thermal stress. Oxidative stress is a major cause for thermal damage of spermatogenic cells and leads to apoptosis and DNA strand breaks (Paul et al. 2009). The effect of thermal stress did not affect the semen quality immediately after exposure because damaged spermatogenic cells do not enter ejaculates for sometime after heat stress. The spermatogenesis takes about 61 days in bulls, and alteration in semen is observable about 2 weeks after heat stress which does not return to normal until up to 8 weeks following the end of heat stress (Hansen 2009).

During the hot summer, breeds in the tropical and subtropical region have more decreased scrotal circumference, testicular consistency, and size and weight than those of the same breeds reared under temperate environmental conditions (Yarney et al. 1990). This reduction in testicular measurements might be due to degeneration in the germinal epithelium. The intensity of sexual behaviour and reaction time is shorter in summer season and the longest in autumn season in male goats. The scrotum has perfect thermoregulatory mechanism in all the animals, but thermal stress has negative effect on sexual desire (libido), ejaculate volume, live sperm percentage, sperm concentration, viability and motility and sperm concentration (Mathevon et al. 1998). Marai et al. (2008) reported decrease in semen-ejaculate volume during thermal stress. In several reports, it has been found that thermal stress decreases the initial motility of spermatozoa in hot climate conditions. Maurya et al. (1999) reported that the serving capacity and libido of animals vary in individual animals in semiarid region of India. Thermal stress reduces the body condition score of the animals which in turn affects the sexual behaviour, scrotum attributes and seminal quality (Maurya et al. 2010).

The stress induced by high ambient temperatures is a well-known factor that can result in higher numbers of damaged or abnormal spermatozoa, and a long duration of high temperature with increased humidity can cause male infertility over a long period of time. High temperature in combination with high humidity increases free radical production. Reactive molecules tend to affect unsaturated fatty acid-rich cell membranes in mammalian spermatozoa, which are considered highly susceptible to peroxidation (Balic et al. 2012). Since the antioxidant defence in sperm cells is very minimal due to the small amount of the cytoplasm in their heads and tails (Bilodeau et al. 2000) in addition to this, reactive oxygen species (ROS) is also able to stimulate the sulfhydryl radical group oxidation in protein molecules as well as DNA fragmentation, thereby altering the structure and function of spermatozoa (Agarwal et al. 2003). Besides the direct effect of heat stress, tissue hypoxia is likely to be one of the consequences of heat stress since the blood supply in the testes cannot compensate for the increased need for tissue metabolism. Several studies in bulls (Newton et al. 2009) have reported the adverse effect of heat stress on sperm motility and morphology, but the exact stages of spermatogenesis during which such defects occur have not yet been fully documented.

The stressful environmental condition affects semen at cellular level and has a negative impact on semen quality. Stress alters cellular function in various tissues and heat shock protein 70 (Hsp70), which, located in reproductive tissues, has critical roles in spermatogenesis (Kamaruddin et al. 2004). Single nucleotide polymorphisms occurring in the Hsp70 promoter region may impact stress tolerance, and haplotypes of Hsp70 were related to cow fertility and heat tolerance (Basirico et al. 2011). The process of spermatogenesis takes approximately 54 days in bulls and 47 days in bucks, and effect of heat stress on sperm output persists for 8 weeks in bulls and 7 weeks in bucks after the termination of heat stress (Meyerhoeffer et al. 1985). Normal spermatogonium proliferation continues to be drastically reduced for weeks even after the end of the heat treatment. The effects of heat on the spermatogonia seem to be dependent on the method, temperature, the duration of heat application and the livestock species.

Since climate change could result in an increase of heat stress, all methods to help animals cope with or, at least, alleviate the impacts of heat stress could be useful to mitigate the impacts of global change on animal responses and performance. Few basic management schemes for reducing the effect of thermal stress may be considered by which one can sustain the productivity of lactating animals during heat stress.

9.9 Milk Production, Heat Stress and Adaptability

Heat stress can impact animal production and profitability in dairy cattle by lowering milk production. The severity of stress and milk production by a cow depends on THI, length of heat stress period, air flow, size of cow, dry matter intake, water availability and coat colour. THI is commonly used to indicate the degree of stress in dairy cattle. THI values suggest that within the normal range up to 70, cattle show optimal performance. In the warning range of THI values 70–72, dairy cow performance is inhibited and the cooling of animals becomes desirable. Critical THI values are 72–78, when milk production is seriously affected. The dangerous category is at the THI values 78–82. A decrease in milk yield is 0.26 kg/day for each increase in THI. Genetic progress in milk production is related closely to an increase in metabolic heat increment, which makes cows more affected by heat stress (Kadzere et al. 2002). Even under excellent management conditions, dairy cows may be exposed to high ambient temperatures, and one of the most common responses of animals to such a stressor is the activation of the hypothalamic–pituitary–adrenal axis. Heat stress has been associated with depressions in milk component percentages (Maurya et al. 2013). Knapp and Grummer (1991) indicated a decreased milk composition with increased maximum daily temperature. Bouraoui et al. (2002) found that milk fat and milk protein were lower for the summer season. Ozrenk and Inci (2008) reported that milk fat, protein and total solid percentages in cow milk were the highest during winter and the lowest during summer. The yield of milk fat of cows exposed to thermal stress declines with decreasing milk yield. Under hot room conditions, the milk fat yield of Holstein cows declined at temperatures above 27 °C. It was reported that in Haryana, cows' contents of milk like milk fat, solid-not-fat (SNF), protein, ash and calcium were highest in winter than summer and rainy season. Studies of the fatty acid composition of milk fat under controlled high temperature showed that any external heat load that raised rectal temperature by 1° or more caused changes in the characteristics of milk fat. In particular, the content of lower-chain fatty acids decreased, whereas the level of palmitic and stearic acids increased. The reason for the shift in the ratio of fatty acids is unknown. Nevertheless, these shifts can be of practical significance as they influence the quality of the milk for cheesemaking.

High ambient temperature appears to have a more marked influence on the SNF content of milk than on milk fat. Thermal stress also appears to bring about some decrease in percentage of lactose and acidity in the milk, lowers its level of pantothenic acid and lowers its freezing point. It increases the pH and levels of ascorbic acid and riboflavin. But it has little effect on salt balance or the carotenoid and vitamin A levels in milk fat. For Karan Fries and Karan Swiss cows, the comfort zone for the maximum milk yield is 7 °C and 25 °C, respectively, and the milk yield per day decreased with increase in temperature and humidity (Shinde et al. 1990). The Jersey crossbreds were less affected by climate than Holstein crossbreds for average milk yield per day. This decrease can be either transitory or longer term depending on the length and severity of heat stress. These decreases in milk production can range from 10 to >25 %. It has been found that

50 % reduction in milk yield is due to reduced feed intake during thermal stress and other 50 % might depend on heat-related lactogenic hormone fluctuations (Johnson 1987). Besides the thermal stress, the decline in milk yield is also dependent upon breed, stage of lactation and feed availability (Bernabucci and Calamari 1998). The effect of heat stress is more in high-yielding cow as compared to low-yielding cow. The experiment conducted in controlled climatic chamber says that because of heat stress, there is 35 % decrease in milk yield during mid-lactation as compared to 14 % decrease in milk at early lactation. The reason for this may be because at early lactation the milk yield is supported by body tissue reserve mobilisation and less by feed intake; however, in mid-lactation the milk yield is mainly supported by feed intake. The calving time during the year also affects the milk yield. Catillo et al. (2002) reported that buffalo calved during summer yields less milk as compared to buffalo calved during other seasons of the year.

The heat stress not only decreases the milk yield in the animals but it also drastically affects the quality of milk (Bernabucci and Calamari 1998). The cow exposed to heat stress produces milk and colostrums with lower percentage of protein and fat (Nardone et al. 1997). In addition to this, the heat stress-exposed animals' milk has lower value of calcium, phosphorus and magnesium and high chloride (Bernabucci and Calamari 1998). A sheep exposed to solar radiation has lower value of fat, fatty acid and protein content in the milk, and a goat also has decreased concentration of lactose, when exposed to severe heat for 4 h duration. The heat stress also drastically affects the length of the fatty acid chain in the milk. Ronchi et al. (1995) reported that a heat-stressed cow has lower proportion of short-chain (C4–C10) and medium-chain (C12–C16) fatty acids and more long-chain fatty acid (C17–C18). He also found out that the heat-stressed cow had 25 % less milk yield than the cow maintained in the thermal comfort zone. These changes in the fatty acid chain may be due to reduced synthesis of this free fatty acid (FFA) in the mammary gland rather than the incorporation of long-chain FFA in the milk. The lower synthesis of short- and medium-chain fatty acid may also be due to the negative energy status of the cow exposed to thermal stress. Nardone et al. (1997) also reported lower level of short- and medium- and higher proportion of long-chain fatty acid in the colostrums of heifers.

The cheese yield and cheese quality are drastically affected by heat stress. The casein content of the milk also reduced during summer in whole milk as well as colostrums (Nardone et al. 1997). The heat stress also had a negative impact on the milk casein (α- and β-casein), and these caseins have 90 % share of total casein present in milk; in addition to this, casein has high numbers of phosphate group. During thermal stress and negative energy balance, phosphorylation is impaired. The lower content of α- and β-casein tends to increase pH of milk and lower phosphorus content during the summer months (Kume et al. 1989).

Since climate change could result in an increase of heat stress, all methods to help animals cope with or, at least, alleviate the impacts of heat stress could be useful to mitigate the impacts of global climate change on animal responses and performance. The effect of heat stress on animals may be reduced by providing suitable shelter and changing microenvironments by mist cooling. Proper nutritional management may also be adopted by supplying of high-energy feeds along with bypass protein, which will help animals to sustain their productivity under heat stress conditions. Physical modification of the environment, genetic development of less sensitive breed to thermal stress and improved nutritional management schemes help combat ill effects of climate change. Supplementation of *Aspergillus oryzae* (AO) increased dry matter (DM) digestibility of high-concentrate diets through enhanced fibre digestion (Gomez Alarcon et al. 1990) which in turn increases milk yield in the dairy cows. The quality and freezability of buffalo semen may be improved by Sephadex filtration of semen (Maurya et al. 2003a, b; Maurya and Tuli 2003). This is an indirect method to improve productivity of buffalo by increasing conception rate per insemination. The recombinant bovine somatotropin has been known for its potential to increase milk production in cattle. Several experiments have been carried out in the USA and proved this fact. The product is in use in the

USA and several other countries. Bovine somatotropin (bST) is a protein hormone produced by the anterior pituitary gland of cattle. The mechanism of action of bST involves a series of orchestrated changes in the metabolism of body tissues so that more nutrients can be used for milk synthesis (Raymond et al. 2009). So it is also an alternative way to increase milk production in cows. During heat stress, the surrounding of the cow may be changed by providing shade and cooling system. In the long run, some fine strategies may be adopted to develop heat stress tolerance breed of cows and buffaloes with the help of upstream reproductive technologies either on cellular level or by genetic manipulations. By improving the nutritional habit of cows, decrease in the milk yield during heat stress may also be minimised up to some extent.

9.10 Conclusion

The climate change is influencing the humidity and temperature level in different geographical areas, and during the twenty-first century, warming is projected to result in decreased production as well as an increase in the number of days when animals will be experiencing heat stress. Climatic fluctuation is going to affect the arid and semiarid areas of the world severely. The climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance. Elevation of ambient temperature affects male reproductive functions deleteriously. Such phenomenon leads to testicular degeneration and reduces percentages of normal and fertile spermatozoa in the ejaculate of males. The ability of the male to mate and fertilise is also affected. Thermal stress generally affects the biological function of animals which in turn changes enzyme activity, hormonal levels, blood biochemicals and reproductive performance of animals. In addition to this, climatic changes also affect milk production of animals. The climate change affects the performance adaptability and profitability of animals by changing the physico-biochemical and hormonal profile of animals. In addition to this, adverse climatic condition also lowers the feed intake and utilisation and in turn lowers production in animals. Ample scope is there to minimise the effect of climatic changes by feeding some additives which reduce stress and also by providing protection to the animals against the harsh climatic conditions. There is urgent need to have refined and improved knowledge to understand complex physiological mechanism, which is responsible for reduction in productive capability of animals during climatic changes.

References

Abdel Samee AM, Maria IFM, Zedan AEB (1997) Males reaction and management under hot climate conditions. In: Proceedings of the 2nd international conference on animal, poultry and rabbit production and health. Institute of Efficient Productivity, Zagazig University, Zagazig, pp 135–151

Agarwal A, Saleh RA, Bedaiwy MA (2003) Role of reactive oxygen species in the pathophysiology of human reproduction. Fertil Steril 79:829–843

Alexander G, Hales JRS, Stevens D, Donnelly JB (1987) Effects of acute and prolonged exposure to heat on regional blood flows in pregnant sheep. J Dev Physiol 9:1–15

Al-Katanani YM, Paula Lopes FF, Hansen PJ (2002) Effect of season and exposure to heat stress on oocyte competence in Holstein cows. J Dairy Sci 85:390–396

Balic IM, Milinkovic Tur S, Samardzija M, Vince S (2012) Effect of age and environmental factor on semen quality, glutathione peroxidase activity and oxidative parameters in simmental bull. Theriogenology 78:423–431

Basirico L, Morera P, Primi V, Lacetera N, Nardone A, Bernabucci U (2011) Cellular thermotolerance is associated with heat shock protein 70.1 genetic polymorphisms in Holstein lactating cows. Cell Stress Chaperones 16:441–448

Bauman DE, Currie WB (1980) Partitioning of nutrients during pregnancy and lactation a review of mechanisms involving homeostasis and homeorhesis. J Dairy Sci 63:1514–1529

Baumgard LH, Rhoads RP, Rhoads ML, Gabler NK, Ross JW, Keating AF, Boddicker RL, Lenka S, Sejian V (2012) Impact of climate change on livestock production. In: Sejian V, Naqvi SMK, Ezeji T, Lakritzand J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GmbH Publisher, Berlin/Heidelberg

Beede DK, Collier RJ (1986) Potential nutritional strategies for intensively managed cattle during thermal stress. J Anim Sci 62:543–554

Ben Salem H, Smith T (2008) Feeding strategies to increase small ruminant production in dry environments. Small Rumin Res 77:174–194
Bernabucci U, Calamari L (1998) Effect of heat stress on bovine milk yield and composition. Zootec Nutr Anim 24:247–257
Bernabucci U, Ronchi B, Lacetera N, Nardone A (2002) Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. J Dairy Sci 85:2173–2179
Bilodeau JF, Chatterjee S, Sirard MA, Gagnon C (2000) Levels of antioxidant defenses are decreased in bovine spermatozoa after a cycle of freezing and thawing. Mol Reprod Dev 55:282–288
Bocquier F, Bonnet M, Faulconnier Y, Guerre-Millo M, Martin P, Chilliard Y (1998) Effects of photoperiod and feeding level on adipose tissue metabolic activity and leptin synthesis in the ovariectomized ewe. Reprod Nutr Dev 38:489–498
Bouraoui R, Lahmar M, Majdoub A, Djemali M, Belyea R (2002) The relationship of temperature humidity index with milk production of dairy cows in a Mediterranean climate. Anim Res 51:479–491
Bridges PJ, Brusie MA, Fortune JE (2005) Elevated temperature (heat stress) in vitro reduces androstenedione and estradiol and increases progesterone secretion by follicular cells from bovine dominant follicles. Domest Anim Endocrinol 29:508–522
Brodsky JL, Chiosis G (2006) Hsp70 molecular chaperones: emerging roles in human disease and identification of small molecule modulators. Curr Top Med Chem 6:1215–1225
Bucklin RA, Hahn GL, Beede DK, Bray DR (1992) Physical facilities for warm climates. In: Van Horn HH, Wilcox, CJ (eds) Large dairy herd management. Am. Dairy Sci. Assoc., Champaign, 61820: 609–618
Catillo G, Macciotta NP, Carretta A, Cappio-Borlino A (2002) Effect of age and calving season on lactation curves of milk production traits in Italian water buffalo. J Dairy Sci 85:1298–1306
Chance B, Sies H, Boveris A (1979) Hydroperoxide metabolism in mammalian organs. Physiol Rev 59:527–605
Chandra G, Aggarwal A (2009) Effect of DL-α-Tocopherol acetate on calving induced oxidative stress in periparturient crossbred cows during summer and winter seasons. Indian J Anim Nutr 26:204–210
Choshniak I, McEwan Jenkinson D, Blatchford DR, Peaker M (1982) Blood flow and catecholamine concentration in bovine and caprine skin during thermal sweating. Comp Biochem Physiol 71C:37–42
Clemens MR, Waller HD (1987) Lipid peroxidation in erythrocytes. Chem Phys Lipids 45:251–268
Collier RJ, Baumgard LH, Lock AL, Bauman DE (2005) Physiological limitations, nutrient partitioning. In: Sylvester-Bradley R, Wiseman J (eds) Yield of farmed species constraints and opportunities in the 21st century. Nottingham University Press, Nottingham, pp 351–377
Collier RJ, Stiening CM, Pollard BC, VanBaale MJ, Baumgard LH, Gentry PC, Coussens PM (2006) Use of gene expression microarrays for evaluating environmental stress tolerance at the cellular level in cattle. J Anim Sci 84:1–13
Collier RJ, Gebremedhin K, Macko AR, Roy KS (2012) Genes Involved in the thermal tolerance of livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GmbH Publisher, Berlin/Heidelberg
Cunningham JC, Klein BG (2007) Endocrinology. In: Textbook of veterinary physiology, 4th edn. Saunders Elsevier, St. Louis, pp 439–448
Du Preez JH, Giesecke WH, Hattingh PJ (1990) Heat stress in dairy cattle and other livestock under Southern African conditions. J Vet Res 57:183–187
Ealy AD, Drost M, Hansen PJ (1993) Developmental changes in embryonic resistance to adverse effects of maternal heat stress in cows. J Dairy Sci 76:2899–2905
Fleshner M, Johnson JD (2005) Endogenous extra cellular heat shock protein 72 releasing signal(s) and function. Int J Hyperth 21:457–471
Fuquay JW (1981) Heat stress as it affects animal production. J Anim Sci 52:164–174
Gomez Alarcon RA, Dudas D, Huber IT (1990) Influence of Aspergillus oryzae on rumen and total tract digestion of dietary components. J Dairy Sci 73:703
Hansen PJ (1994) Causes and possible solutions to the problem of heat stress in reproductive management of dairy cows. In: Proceedings of the national reproductive symposium, Pittsburgh
Hansen PJ (2009) Effect of heat stress on mammalian reproduction. Philos Trans R Soc B 364:3341–3350
Hansen JRS, Arechiga CF (1999) Strategies for managing reproduction in the heat stressed dairy cow. J Dairy Sci 77:36–50
Haque N, Ludri A, Hossain SA, Ashutosh M (2012) Alteration of metabolic profiles in young and adult Murrah buffaloes exposed to acute heat stress. Int J Appl Anim Sci 1:23–29
Hayes B, Bowman P, Chamberlain A, Goddard M (2009) A validated genome wide association study to breed cattle adapted to an environment altered by climatic change. PLoS One 4:e6676
Horowitz M (2002) From molecular and cellular to integrative heat defence during exposure to chronic heat. Comp Biochem Physiol Part A 131:475–483
Ireland HE, Leoni F, Altaie O, Birch CS, Coleman RS, Hunter Lavin C, Williams JJH (2007) Measuring the secretion of heat shock proteins from cells. Methods 43:183
Johnson HD (1987) Bioclimate effects on growth, reproduction and milk production. In: Bioclimatology and the adaptation of livestock. Elsevier, Amsterdam. Part II, chapter 3
Joshi BC, Tripathy KC (1991) Heat stress effect on weight gain and related physiological responses of buffalo calves. J Vet Physiol Allied Sci 10:43–48

Kadzere CT, Murphy MR, Silanikove N, Maltz E (2002) Heat stress in lactating dairy cows a review. Live Stock Prod Sci 77:59–91
Kamal TH (1975) Heat stress concept a new tracer methods for heat tolerance in domestic animals. Ist Science congress on peaceful use atomic energy for Scientific and Economic Development. Baghdad Iraq Proceeding of IAEA/FAO Vienna
Kamaruddin M, Kroetsch T, Basrur PK, Hansen PJ, King WA (2004) Immunolocalization of heat shock protein 70 in bovine spermatozoa. Andrologia 36:327–334
Knapp DM, Grummer RR (1991) Response of lactating dairy cows to fat supplementation during heat stress. J Dairy Sci 74:2573–2579
Koubkova M, Knizkova I, Kunc P, Hartlova H, Flusser J (2002) Influence of high environmental temperatures and evaporative cooling on some physiological haematological and biochemical parameters in high yielding dairy cows. Czech J Anim Sci 47:309–318
Kumar A (2005) Status of oxidative stress markers in erythrocytes of heat exposed cattle and buffaloes. MVSc thesis, NDRI Deemed University, Karnal
Kume S, Takahashi S, Kurihara M, Aii T (1989) The effects of a hot environment on the major mineral content in milk. Jpn J Zootech Sci 60:341–345
Lefcourt AM, Bitman J, Wood DL, Stroud B (1986) Radiotelemetry system for continuously monitoring temperature in cows. J Dairy Sci 69:237–242
Lemerle C, Goddard ME (1986) Assessment of heat stress in dairy cattle in Papua New Guinea. Trop Anim Health Prod 18:232–242
Macrae AI, Whitaker DA, Burrough E, Dowell A, Kelly JM (2006) Use of metabolic profiles for the assessment of dietary adequacy in UK dairy herds. Vet Rec 159:655–661
Mann T, Lutwak mann C (1981) Biochemistry of spermatozoa chemical and functional correlations in ejaculated semen. In: Mann T (ed) Male reproductive function and semen. Themes and trends in physiological and biochemical and investigative andrology. Lutwak Mann Spring Verlag, Berlin
Marai IFM, El-Darawany A-HA, Ismail E-SAF, Abdel-Hafez MAM (2006) Tunica dartos index as a parameter for measurement of adaptability of rams to subtropical conditions of Egypt. Anim Sci J 77:487–494
Marai IFM, EI Darawany AA, Fadiel A, Abdel Hafez MAM (2007) Physiological traits as affected by heat stress in sheep a review. Small Rumin Res 71:1–12
Marai IFM, El Darawany AA, Fadiel A, Abdel-Hafez MAM (2008) Reproductive performance traits as affected by heat stress and its alleviation in sheep a review. Trop Subtrop Agroecosyst 8:209–234
Mathevon M, Buhr MM, Dekkers JCM (1998) Environmental management and genetic factors affecting semen production in Holstein bulls. J Dairy Sci 81:3321–3330
Matsuzuka T, Sakamoto N, Ozawa M, Ushitani A, Hirabayashi M, Kanai Y (2005) Alleviation of maternal hyperthermia induced early embryonic death by administration of melatonin to mice. J Pineal Res 39:217–223. doi:10.1111/j.1600-079X.2005.00260.x
Maurya VP, Tuli RK (2003) Post thaw thermal resistance test on motility and acrosomal integrity of filtered frozen spermatozoa of Murrah buffalo bull. Asian-Australas J Anim Sci 16:1424–1428
Maurya VP, Naqvi SMK, Joshi A, Mittal JP (1999) Dominance libido and serving capacity of Garole rams under semi-arid region of Rajasthan. Indian J Anim Sci 69:773–775
Maurya VP, Tuli RK, Pardeep S (2003a) Effect of filtration on freezability and acrosomal integrity of Murrah buffalo bull semen. Indian J Anim Sci 73:983–985
Maurya VP, Tuli RK, Goyal RL (2003b) Effect of buffer composition sephadex grade and column size on filtration based quality improvement of semen from Murrah buffalo bull. Asian-Australas J Anim Sci 16:165–171
Maurya VP, Naqvi SMK, Mittal JP (2004) Effect of dietary energy level on physiological response and reproductive performance of Malpura sheep in the hot semi-arid regions of India. Small Rumin Res 55:117–122
Maurya VP, Naqvi SMK, Joshi A, Gulyani R, Mittal JP (2005) Effect of thermal stress on sexual behavior of superovulated Bharat Merino ewes. Asian-Australas J Anim Sci 18:1403–1406
Maurya VP, Naqvi SMK, Joshi A, Mittal JP (2007) Effect of high temperature stress on physiological responses of Malpura sheep. Indian J Anim Sci 77:1244–1247
Maurya VP, Kumar S, Kumar D, Gulyani R, Joshi A, Naqvi SMK, Arora AL, Singh VK (2009) Effect of body condition score on reproductive performance of Chokla ewes. Indian J Anim Sci 79:1136–1138
Maurya VP, Sejian V, Kumar D, Naqvi SMK (2010) Effect of induced body condition score differences on sexual behavior scrotal measurements, semen attributes and endocrine responses in Malpura rams under hot semi-arid environment. J Anim Physiol Anim Nutr 94:e308–e317
Maurya VP, Naqvi SMK, Joshi A, Mittal JP, Singh VK (2011) Influence of thermal stress on estrus behaviour and fertility in native Malpura sheep under semi-arid region of India. Indian J Anim Sci 81:15–18
Maurya VP, Sejian V, Kumar K, Singh G, Naqvi SMK (2012) Walking stress influence on livestock production. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GmbH Publisher, Berlin/Heidelberg
Maurya VP, Singh G, Sejian V, Sarkar M (2013) Temperature effects on milk composition and production in Livestock. In: V Prasada Rao, G Girish Varma (eds) DST SERB Sponsored training manual on

Fundamentals of Livestock Meteorology, vol I GSLH. Published by Centre for Animal Adaptation to Environment and Climate Change Studies Kerala Veterinary and Animal Sciences University Mannuthy 680651 Thrissur Kerala India

McDonald LE, Pineda MH (1989) Veterinary endocrinology and reproduction. Lea & Febriger, Philadelphia/London

Meyerhoeffer DC, Wettemann RP, Coleman SW, Wells ME (1985) Reproductive criteria of beef bulls during and after exposure to increased ambient temperature. J Anim Sci 60:352–357

More T, Singh M, Rai AK (1980) Observation on excretory pattern of sodium, potassium and water at different temperature. Indian J Anim Sci 50:182–186

Murray MT (1997) Male infertility: a growing concern. Am J Nat Med 4:9–16

Naqvi SMK (1987) Physiological adaptation of sheep during energy crisis and thermal stress. PhD thesis, submitted to Kurukshetra University, Kurukshetra

Naqvi SMK, Hooda OK (1991) Influence of thermal, nutritional and exercise stress on some blood parameters of native and crossbred sheep. Indian J Anim Sci 61:660–662

Naqvi SMK, Maurya VP, Gulyani R, Joshi A, Mittal JP (2004) The effect of thermal stress on superovulatory response and embryo production in Bharat merino ewes. Small Rumin Res 55:57–63

Nardone A, Lacetera N, Bernabucci U, Ronchi B (1997) Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. J Dairy Sci 80:838–844

Newton LD, Kastelic JP, Wong B, Van der Hoorn F, Thundathil J (2009) Elevated testicular temperature modulates expression patterns of sperm proteins in Holstein bulls. Mol Reprod Dev 76:109–118

Nienaber JA, Hahn GL, Eigenberg RA (1999) Quantifying livestock responses for heat stress management a review. Int J Biometerol 42:183–188

Ozawa M, Tabayashi D, Latief TA, Shimizu T, Oshima I, Kanai Y (2005) Alterations in follicular dynamics and steroidogenic abilities induced by heat stress during follicular recruitment in goats. Reproduction 129:621–630

Ozrenk E, Inci SS (2008) The effect of seasonal variation on the composition of cow milk in Van Province. Pak J Nutr 7:161–164

Paul C, Teng S, Saunders PTK (2009) A single mild transient scrotal heat stress causes hypoxia and oxidative stress in mouse testes which induces germ cell death. Biol Reprod 80:913–919

Paula Lopes FF, Chase CC Jr, Al-Katanani YM, Krininger CE III, Rivera RM, Tekin S, Majewski AC, Ocon OM, Olson TA, Hansen PJ (2003) Genetic divergence in cellular resistance to heat shock in cattle: differences between breeds developed in temperate versus hot climates in responses of preimplantation embryos, reproductive tract tissues and lymphocytes to increased culture temperatures. Reproduction 125:285–294

Pérez Crespo M, Ramírez MA, Fernández González R, Rizos D, Lonergan P, Pintado B, Gutiérrez-Adán A (2005) Differential sensitivity of male and female mouse embryos to oxidative induced heat stress is mediated by glucose 6 phosphate dehydrogenase gene expression. Mol Reprod Dev 72:502–510. doi:10.1002/mrd.20366

Raizada NS, Sastry NSR, Pal RN, Juneja IJ (1980) Studies on the effect of certain summer managemental practices on lactating Murrah buffaloes 3: physiological reactions and some attributes of blood. Haryana Agric Univ J Res 10:442–447

Raymond R, Bales CW, Bauman DE, Clemmons D, Kleinman R, Lanna D, Nickerson S, Sejrsen K (2009) Recombinant Bovine Somatotropin (rbST) a safety assessment. ADSA-CSAS-ASAS Joint Annual Meeting, Montreal

Rhoads ML, Rhoads RP, Van Baale MJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Baumgard LH (2009) Effects of heat stress and plane of nutrition on lactating Holstein cows I production metabolism and aspects of circulating somatotropin. J Dairy Sci 92:1986–1997

Riedel W, Layka H, Neeck G (1998) Secretory pattern of GH TSH thyroid hormones ACTH cortisol FSH and LH in patients with fibromyalgia syndrome following systemic injection of the relevant hypothalamic releasing hormones. Zeitschrift Fur Rheumatologie 57(suppl 2):81–87

Ronchi B, Bernabucci U, Lacetera N, Nardone A (1995) Milk fatty acid composition in cows exposed to hot environment. In: Proceedings of XI Congress Associazione Scientifical Produzione Animale, pp 353–354

Ronchi B, Stradaioli G, Verini Supplizi A, Bernabucci U, Lacetera N, Accorsi PA, Nardone A, Seren E (2001) Influence of heat stress and feed restriction on plasma progesterone, estradiol 17b LH FSH prolactin and cortisol in Holstein heifers. Live Prod Sci 68:231–241

Roth Z, Meidan R, Braw Tal R, Wolfenson D (2000) Immediate and delayed effects of heat stress on follicular development and its association with plasma FSH and inhibin concentration in cows. J Reprod Fertil 120:83–90

Roth Z, Meidan R, Shaham Albalancy A, Braw Tal R, Wolfenson D (2001) Delayed effect of heat stress on steroid production in medium-sized and preovulatory bovine follicles. Reproduction 121:745–751

Roy KS, Prakash BS (2007) Seasonal variation and circadian rhythmicity of the prolactin profile during the summer months in repeat-breeding Murrah buffalo heifers. Reprod Fertil Dev 19:569–575

Sakatani M, Kobayashi S, Takahashi M (2004) Effects of heat shock on in vitro development and intracellular oxidative state of bovine preimplantation embryos. Mol Reprod Dev 67:77–82

Sejian V, Maurya VP, Naqvi SMK, Kumar D, Joshi A (2010a) Effect of induced body condition score differences on physiological response, productive and reproductive performances of Malpura ewes kept in a hot semi arid environment. J Anim Physiol Anim Nutr 94:154–161

Sejian V, Maurya VP, Naqvi SMK (2010b) Adaptive capability as indicated by endocrine and biochemical responses of Malpura ewes subjected to combined stresses (thermal and nutritional) under semi arid tropical environment. Int J Biometeorol 54:653–661

Sejian V, Maurya VP, Naqvi SMK (2010c) Adaptability and growth of Malpura ewes subjected to thermal and nutritional stress. Trop Anim Health Prod 42:1763–1770

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2012a) Effect of multiple stresses on growth physiological response blood biochemical and endocrine responses in Malpura ewes under semi arid tropical environment. Trop Anim Health Prod 45:107–116

Sejian V, Maurya VP, Naqvi SMK (2012b) Effect of walking stress on growth, physiological adaptability and endocrine responses in Malpura ewes under semi arid tropical environment. Int J Biometeorol 56:243–252

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2012c) Effect of multiple stresses (thermal nutritional and walking stress) on the reproductive performance of Malpura ewes. Vet Med Int. doi:10.1155/2012/471760

Sejian V, Maurya VP, Sharma KC, Naqvi SMK (2012d) Concept of multiple stresses and its significance on livestock productivity. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GMbH Publisher, Berlin/Heidelberg

Sethi RK, Bharadwaj A, Chopra SC (1994) Effect of heat stress on buffaloes under different shelter strategies. Indian J Anim Sci 64:1282–1285

Shinde S, Taneja VK, Singh A (1990) Association of climatic variables and production and reproduction traits in crossbreds. Indian J Anim Sci 15:29–31

Singh SV, Upadhyay RC, Ashutosh, Hooda, OK, Vaidya, MM (2011) Climate change impacts on reproductive pattern of cattle and buffaloes review. Wayamba J Anim Sci WJASID 1322125457

St Pierre NR, Cobanov B, Schnitkey G (2003) Economic loss from heat stress by US livestock industries. J Dairy Sci 86:52–77

Todini L, Malfatti A, Valbonesi A, Trabalza Marinucci M, Debenedetti A (2007) Plasma total T_3 and T_4 concentrations in goats at different physiological stages as affected by the energy intake. Small Rumin Res 68:285–290

Trevisan M, Browne R, Ram M, Muti P, Freudenheim J (2001) Correlates of markers of oxidative status in the general population. Am J Epidemiol 154:348–356

Tytell M (2005) Release of heat shock proteins (HSPS) and the effects of extracellular HSPS on neural cells and tissues. Int J Hyperth 21:445–455

Uetake K, Ishiwata T, Abe N, Eguchi Y, Tanaka T (2006) Hormonal and metabolic relation to restraint and human handling in growing fattening steers. Anim Sci J 77:370–374

Verma DN, Lal SN, Singh SP, Prakash O (2000) Effect of season on biological response and productivity of buffaloes. Int J Anim Sci 15:237–244

Wallace JM, Regnault TR, Limesand SW, Hay WW Jr, Anthony RV (2005) Investigating the causes of low birth weight in contrasting ovine paradigms. J Physiol 565:19–26

Wang JZ, Sui HS, Miao DQ, Liu N, Zhou P, Ge L, Tan J (2009) Effects of heat stress during in vitro maturation on cytoplasmic versus nuclear components of mouse oocytes. Reproduction 137:181–189

West JW, Hill GM, Fernandez JM, Mandebvu P, Mullinix BG (1999) Effects of dietary fiber on intake milk yield and digestion by lactating dairy cows during cool or hot, humid weather. J Dairy Sci 82:2455–2465

Yarney TA, Sanford LM, Palmer WM (1990) Pubertal development of ram lambs: body weight and testicular size measurements as indices of postpubertal reproductive function. J Anim Sci 70:139–147

Zimbelman RB, Muumba J, Hernandez LH, Wheelock JB, Shwartz G, O'Brien MD, Baumgard LH, Collier RJ (2007) Effect of encapsulated niacin on resistance to acute thermal stress in lactating Holstein cows. J Dairy Sci 86(Suppl. 1):231 (Abstr)