Review on Effect of Stress on Animal Productivity and Response of Animal to Stressors

Mohammed Endris and Endris Feki
Afar Pastoral and Agro-Pastoral Research Institute, P.O. Box 16, Samara, Ethiopia

Key words: Stress, stressors, response, animal, productivity

Corresponding Author:
Mohammed Endris
Afar Pastoral and Agro-Pastoral Research Institute, P.O. Box 16, Samara, Ethiopia

Page No.: 1-14
Volume: 20, Issue 1, 2021
ISSN: 1680-5593
Journal of Animal and Veterinary Advances

Abstract: This study aims to review and identify stressors that affect the productivity of animals; knowledge on effects or implications of stress on animal productivity, understanding the response of the animal to the stressors and strategies for alleviating stress in farm animals. Farm animals are regularly faced with different stressors. Most stressful conditions including cold, heat, handling, transporting, temperament, introduction to a new herd or flock, diseases and parasites. Stress is a reflex reaction revealed by the inability of an animal to cope with its environment which may lead to many unfavorable consequences, ranging from discomfort to death. It covers the behavioral and biological responses to a wide range of abiotic stressors such as social interactions or rough handling, common farm practices (castration, dehorning, teeth clipping, shoeing, weaning crowding, etc.) improper feeding, exposure to adverse climatic conditions, exercise, work and transport, etc. Stress reduces the fitness and productivity of the animal. Little is known about the signs of stressed animals in turn, almost all farmers lose their animals through death. Moreover, in the future population growth, urbanization and income growth in developing countries are fuelling a massive global increase in demand for food of animal origin. However, the effect of stress has a great impact on the productivity of farm animals. The issue must receive more research attention in minimizing farm animal stress and optimizing product yield and quality.

INTRODUCTION

In animal husbandry, stress has been conceived as a reflex reaction that occurs ineluctably when animals are exposed to adverse environmental conditions and which is the cause of many unfavorable consequences ranging from discomfort to death[1]. There are environmental forces that are continuously acting upon animals that disrupt homeostasis, resulting in new adaptations that can be either detrimental or advantageous to man's interest. The natural environment is composed of various potentially hostile stressors. It is a basic requirement of life that the cells of an organism must be maintained within closely defined physiological limits. The maintenance of a constant interior milieu results from physiological and behavioral homeostatic adaptations. The physiological regulation of homeostasis is achieved by complex endocrine interactions, principally by the hormones secreted from the adrenal glands.

Stress is a reflex reaction revealed by the inability of an animal to cope with its environment which may lead to many unfavorable consequences, ranging from discomfort to death. It covers the behavioral and biological responses to a wide range of abiotic stressors such as social interactions or rough handling, common farm practices (castration, dehorning, teeth clipping, shoeing, weaning crowding, etc) improper feeding, exposure to adverse climatic conditions, exercise work and transport, etc. Stressors can originate from within an individual (endogenous) or from the environment (exogenous). Stress-triggering stimuli are not necessarily painful but psychological states such as fear or anxiety also activate physiological responses. Once an animal perceives a threat, it develops a behavioral, autonomic, endocrine or immune response to maintain homeostasis. In case an animal is unable to withstand stress, the consequences will be abnormal biological functions and the development of pathologies. Stress responses are related not only to the nature and the intensity of the triggering stimulus but also to individual response tendencies or temperament[2].

The inability of livestock farmers to identify or recognize environmental factors and management practices that pose stress to farm animals may result in lower performance and reproductive ability of animals leading to a shortage of animal and animal products supply. Understanding of stressors that impact domestic farm animal productivity and management practices that can relieve stress within the environment will enhance animal comfort and maintain a secure, productive and low-cost food supply[3]. Therefore, this study aims to review and identifying stressors that affect the productivity of animals, knowledge on the effects or implications of stress on animal productivity, understanding the response of the animal to the stressors and strategies for alleviating stress in farm animals.

A stressor that affects the productivity of animals: Stressors can be conveniently classified into social stressors resulting from the interaction with individuals of the same species and stressors related to handling by humans. Environmental stress due to climatic factors but extends to nutrition, housing and any stimuli that demand a response from the animal to adapt to new circumstances. For many domestic species, attachments between one animal and another are important in a variety of social contexts and management practices relating to such attachments can profoundly affect the welfare of the animals. The separation of mother and young at weaning is probably a source of considerable distress. If young are weaned after they have learned to take solid food they may display only a slight temporary upset. Earlier weaning may have more prolonged effects. Lambs taken from their dams and allowed free access to artificial teats spend time sucking the scrotum, navel and ears of other lambs. The same is true of calves and piglets weaned as late as 3 weeks frequently perform a sustained rubbing of the bellies of their pen-mates, sometimes interfering with feeding, elimination and other behavior. In some systems of management, piglets weaned a few days after birth may consume little food for several days. Abnormal aggression and hyperactivity may develop under these conditions. Since piglets show an adrenocortical response to starvation from as early as one day of age, it seems likely that very early weaning brings about a classical physiological state of stress.

Environmental and management stressors: Environmental stress is not limited to climatic factors but extends to nutrition, housing and any stimuli that demand a response from the animal to adapt to new circumstances. Environmental stressors that affect reproductive efficiency, adverse effects of heat stress are most dramatic and the most documented. Other stressors include animal handling techniques, environment, transportation, disease, management techniques and changes in day length among others.

Cold stress: According to Robert and Gilbert reported that cold stress during periods of inclement weather is largely a problem for free stall-housed dairy cattle that must increase energy intake to maintain body heat. In this instance, thyroid hormones may increase to enhance dry-matter intake. However, regardless of exact pathophysiology, reproductive performance is diminished. Cows are reluctant to interact, tend to lose weight, may suffer production losses as more energy is directed toward body heat and do not like to move about on icy floors and hard irregular surfaces created by frozen manure on floors. Roughened hair coats and losses in body condition are observed in many animals in cold-stressed herds. Heat detection and conception suffer. A more energy-dense ration may need to be formulated when herds suffer from cold stress-induced fertility problems, metabolic problems or production losses.

Heat stress: Heat stress is one of the leading causes of decreased production and fertility in Nebraska dairy cattle during the summer months. These losses are apparent in the decreased amount of milk shipped, increased days open and decreased breedings per conception. Some heat stress is unavoidable but effects can be minimized if certain management practices are followed[4]. High ambient temperatures, high direct and indirect solar radiation and humidity are environmental stressing factors that impose strain on animals. Despite having well-developed mechanisms of thermoregulation, ruminants do not maintain strict homeothermy under heat

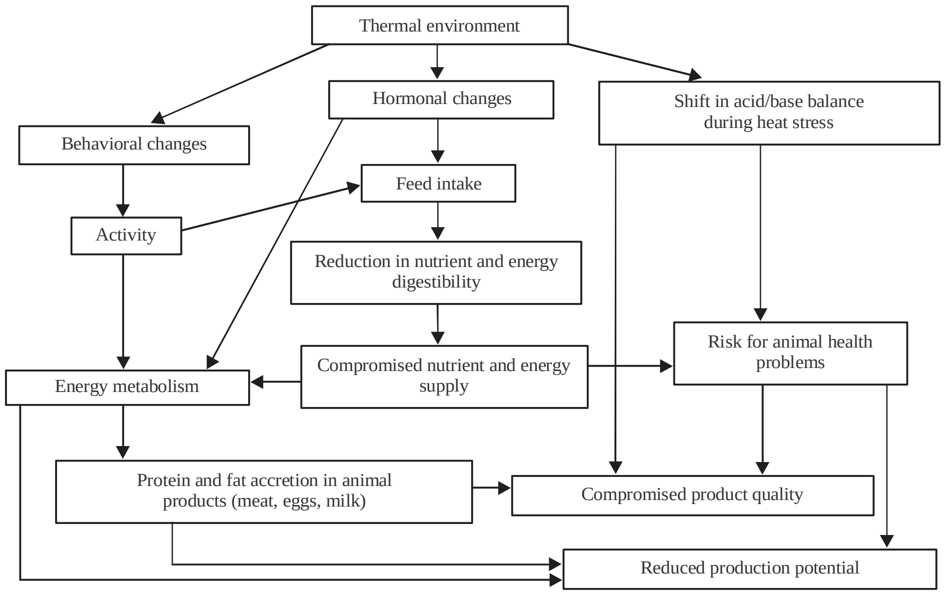

Fig. 1: Potential mode of action of inconvenient thermal environment on the production potential and product quality of livestock[5]

stress. There is unequivocal evidence that hyperthermia is deleterious to any form of productivity, regardless of breed and stage of adaptation. The best-recognized effect of raised body temperature is an adaptive depression of the metabolic rate associated with reduces appetite. Thus, in domestic ruminants, a rise in body temperature marks the transition from aversive stage to noxious stage. Factors such as water deprivation, nutritional imbalance and nutritional deficiency may exacerbate the impact of heat stress (Fig. 1).

The stress of a hot environment lowers reproductive efficiency in farm animals. Hot weather causes heat stress in animals. Although, effects are more severe in hot climates, dairy cattle in areas with relatively moderate climates are also exposed to periods of heat stress. The resultant decrease in milk production and reproductive efficiency can be offset by the implementation of a program consisting of cooling through ventilation, spray and fans. The economic benefit should be determined before the installation of equipment to reduce heat stress.

Heat stress will delay puberty in both males and females. Puberty was delayed in Hereford heifers reared at 27°C (80°F) as compared with others reared at 10°C (50°F). Similarly, puberty was delayed in Jersey bulls that were exposed to a 35°C (95°F) for 8 h a day. Heat stress delays puberty by depressing appetite and slowing growth rate. Hot conditions in most parts of the world are severe enough to lower semen quality resulting in a lower conception rate. Spermatozoa in semen collected from bulls during the summer/hot periods show an increase in abnormal morphology and reduce binding to glycosaminoglycans such as heparin. At a temperature of 40°C, it was found that as little as 12 h of exposure proved critical to optimum spermatogenesis and a decline in semen quality occurred after a week at this temperature. Field studies temperatures >18°C, eleven out of twelve Shorthorn bulls were culled either based on poor semen quality or abnormalities of the genitalia while only one of ten Africander bulls was culled. Heifers maintained under temperatures of 10°C reached sexual maturity at 10 months while those kept under temperatures of 27°C matured at 13 months, possibly as a result of reduced growth at high temperatures. Delayed onset of puberty, particularly, in Bos indicus cattle, constitutes a major limiting factor in the breeding of yearling heifers for beef production.

Animal handling and transporting: One stressor which is easily eliminated is the improper handling of calves by caretakers which can cause both behavioral and physiological stress. This can sometimes adversely affect reproduction. Rearing gilts in confined pens as compared with group pens has delayed puberty. Beef cows, isolated and confined in a corral either before or after insemination. Transporting animals to a new location has altered oestrus cycles and delayed ovulation, as has constraints and mild shock. These examples illustrate that animal handling techniques that are psychologically disturbing to animals will sometimes adversely affect reproductive efficiency.

According to Hemsworth and Coleman[6], a stock person's attitude and behavior have a significant effect on animal's fear, welfare and productivity. Human behavior eliciting certain animal responses have been measured as positive or negative. A negative handling behavior such as slaps, hits, fast movements, shouting and noise will cause an increase in fear in the animal, resulting in avoidance, stress and handling difficulties. Positive stock person's behaviors such as pats, strokes, talking, hand resting on the back, slow and deliberate movements will reduce the animal's level of fear of humans and result in animal which is less stressed and are easier to handle. These effects have been demonstrated in many farm animal species. Negative handling significantly increases an animal's cortisol response, that is; stress. Animals exposed to positive handling had a much shorter flight distance, acute cortisol responses were significantly lower compared to animals that had received negative handling. A study conducted by Hemsworth and Coleman[6], showed that the growth rate of positively handled pigs was 455 g day^{-1}, whereas it was only 404 g day^{-1} in pigs negatively handled. The growth rate of inconsistent pigs was 420 g day^{-1}. In this situation, the growth rate was reduced due to the animal stress response (cortisol concentrations were elevated in inconsistent and negatively handled pigs)[6]. A similar study was carried out in laying hens, looking at the negative effects of negative handling. The corticosterone stress levels were much higher in hens handled negatively, than in positively handled hens. Subsequently, egg production in the hens was 8% higher in hens that had a positive human-animal relationship. The number of studies across species with a strong correlation between stress and negative handling leaves no doubt that negative handling evokes stress, affecting animal welfare and production[6].

Reducing stress during handling will provide advantages of increased productivity and maintaining meat quality. It was indicated that cattle that become agitated and excited in the squeeze chute have significantly lower weight gains, tougher meat and more borderline dark cutters. Agitation and excitement in the squeeze chute are influenced by both genetic factors and the animal's previous handling experiences. Reports from commercial feedlots indicated that quiet handling methods help improve productivity. Short-term stressors that occur during handling and transport have been shown to interfere with the biological mechanisms of both reproduction and immune functions. Electric prods, restraint and other handling stressors will lower female reproductive functions. In both pigs and cattle, transport or restraint stress lowers immune functions. In cattle, the stress imposed by transit has a greater detrimental effect on the animal's physiology than the stress of feed and water deprivation for the same length of time. Transport stress can also lower rumen function compared to controls subjected to feed withdrawal. In sheep, chased by dogs, handlings and sorting, two or three weeks after mating caused early embryonic losses.

Temperament: Animal producers and caretakers are probably familiar with the 'fight or flight' concept which is the ability of an animal to react quickly to a real or perceived threat (stressor). How cattle react to threats, humans, a fearful situation or a novel, stressful environment, is its temperament. The temperamental animal can be excitable, stress-responsive or wild and may injure their caretakers, other animals or themselves and they may damage facilities. Temperament is a heritable trait; therefore the livestock industry may apply selection tools to improve their herds, protect animal well-being and enhance profitability. New-born Brahman calves that are prenatally stressed are less competent to survive the bacterial disease than non-stressed calves. The same author investigates the influence of stress and temperament on the performance of beef cattle. Their research team has studied these relationships in weaning age cattle and is currently studying the effect of prenatal stress on postnatal temperament, health and performance of beef calves. Besides stress response helps an animal maintain balance or homeostasis. Temperamental animals are more stress-responsive than their calmer herd mates. Amongst the environmental factors, hot ambient temperature has a significant impact on the productive and reproductive performance of livestock species. Several factors are responsible for causing heat stress and major factors are high ambient temperature and high humidity

Disease and parasite: Livestock diseases can cause direct losses (deaths, stunting, reduced fertility and changes in herd structure) and indirect losses (additional costs for drugs and vaccines, added labor costs and profit losses due to denied access to better markets and use of suboptimal production technology) in revenue[7]. From the point of view of producers, livestock diseases are essentially an economic problem. Diseases that reduce production, productivity and profitability are associated with the cost of their treatment, disruption of local markets, international trade and exacerbate poverty in rural, local and regional communities. At the biological level, pathogens compete for the productive potential of animals and reduce the share that can be captured for human purposes[7, 8]. Docking and castration were managed as severe stressors that lambs may encounter as a part of routine husbandry. Shearing is necessary for the well-being of sheep as in hot weather sheep with too much wool is extremely susceptible to heat stress. Shearing keeps stained wool and mud contaminated wool separate from new fleece growth, however, it could be of negative effect when applied at an inappropriate time. Another stress factor could result from shearing when an animal is exposed to wet weather either under severe cold or intense hot sunshine. Shearing itself is a stress on the animal.

The response of animal to stressors (stress factors): Stress responses are any responses that an organism makes or goes through in response to a stressor that is causing stress. Stress is any disturbance that imbalances the internal environment of an organism also known as homeostasis[9]. There are two major types of stressors that cause stress to animals: abiotic stressors and biotic stressors. Abiotic stressors are any ecological, geological or climatological change, that causes stress to the animal such as increased temperatures and natural disasters[10]. Biotic stressors are living things-related complications that cause stress; these include dominance, pollution, infection, social pressures and competition.

Broadly, adaptation is a non-genetic (short-term or phenotypic) and genetic (long-term or generational) response to a challenge (stressor). Non-genetic responses to a stressor may be short term such as reduced feed intake and increased respiration rates when exposed to high ambient temperature. However, short-term responses also have a genetic basis with some animals better able to cope than others when exposed to the same stressors. Many management strategies are short-term responses to acute challenges such as the provision of shade and dietary manipulation. These reduce the challenge but don't lead to genetic change. Productivity gains via targeted trait selection of ruminants are well documented. However, the selection of animals for high levels of production has increased animal susceptibility to environmental challenges. For example, it is well accepted that high producing dairy cows are more susceptible to heat stress than low producing cows. Using lower production cows could reduce heat stress, lower milk output and lower input costs. However, there would be a concentration of maintenance costs with a reduction in efficiency and increased greenhouse gas intensity. Optimum animal production is easiest but not necessarily the most economical, to achieve under controlled environmental conditions which is more often seen in non-ruminant compared with ruminant production systems.

The challenges are many and do not always have a direct effect on animal performance. For example, chronic exposure to hot conditions may result in poorer pasture quantity and quality leading to poorer nutrition and nutritional outcomes which results in reproductive failure, poor growth and increased disease risks. In this arena, animal adaptation is not necessarily paramount since it is more about getting nutrition correct and thus a whole farm approach is required[11]. The challenges are, to determine if there is a need for adaptation, a need for improved animal management (i.e., management and resource adaptation) or both.

There are different types of stress responses in an animal in response to stressors: Morphological response, Behavioral responses, Physiological responses, Neuro-endocrine response, Psychological responses and/or Physical responses[12, 13]. The response depends on the choice the animal partakes in when it is faced with a danger that causes distress. There are two possible choices that an organism may choose when stress is encountered: fight or flight responses; the choice is based on careful evaluation of the situation that would derive a response[9] (Fig. 2).

Morphological response: According to the study cited by Sejian *et al*.[14], morphological traits in livestock are highly important from the adaptation point of view as they directly influence the heat exchange mechanisms (cutaneous convection, radiation and evaporation) between the animal and the surrounding environment[15]. Breed differences for morphological adaptive traits are evident in some species[15]. Coat color was one of the important morphological traits which impart an adaptive ability to heat-stressed livestock. For example, light-/white-coloured coats in animals are recognized as being advantageous in hot tropical regions as it reflects 50-60% of direct solar radiation compared with the dark-colored animals[15]. Highly pigmented skin protects the deep tissues from direct short wave UV radiation by blocking its penetration. Besides, coat length, thickness and hair density also affect the adaptive nature of animals in tropical regions where short hair, thin skin and fewer hair follicles per unit area are directly linked to higher adaptability to hot conditions. Indigenous sheep breeds adapted to arid and semi-arid regions possess morphological characteristics such as carpet type wool which helps to provide better protection from direct solar radiation and this type of wool also allows effective cutaneous evaporative heat dissipation[16]. The fat tail observed in sheep is also recognized as a morphological adaptation for better heat transfer[17].

Cutaneous evaporation is recognized as the most important mode of heat dissipation in cattle. Thus, higher diameter, volume, perimeter and density of sweat glands in animals are considered to be good adaptive traits for hot environments[18]. Smaller body size of tropical indigenous cattle breeds (as compared with English and European cattle) is recognized as being beneficial for surviving in harsh environments, due in part to the smaller animal's lower feed and water requirements. Also, cattle breeds that are indigenous to the tropical regions possess efficient testicular thermoregulatory mechanisms during heat stress conditions through higher ratios of testicular artery length and volume to the volume of testicular tissue[19].

Behavioral response: Behavioral adaptation is recognized as the first and foremost response adopted by animals to reduce heat load[21, 22]. One of the quickest and

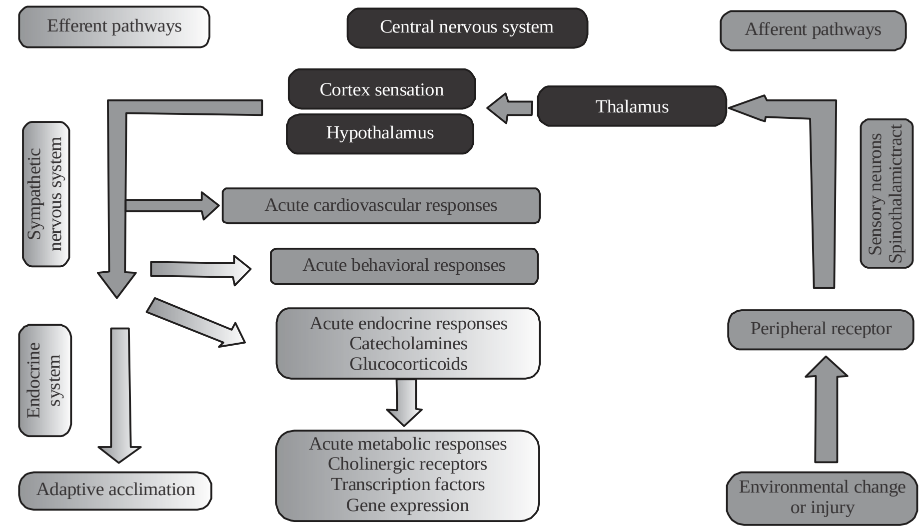

Fig. 2: Pathways of the stress response[20]

profound behavioral changes seen in heat-stressed animals is shade seeking. The stressed animals attempt to ameliorate the negative effects of direct heat load by using shade whenever they can access it. Research clearly shows that dairy cattle use shade in warm environments and that the frequency of this behavior was found to increase with higher air temperature and solar radiation[20]. However, tropical indigenous breeds were observed to be highly adapted to direct heat stress, spending more time for grazing than resting in shade.

Another important and well-documented behavioral response to enhanced heat load loss in ruminants is reduced feed intake. Recent studies established lower feed intake in various farm animals including cattle, sheep and goats during summer[21, 22]. Lower feed intake in warm conditions is identified as an adaptive response to regulate the internal metabolic heat production in heat-stressed animals. Similarly, Valente *et al*.[23] reported reduced feed intake in both heat-stressed Nellore and Angus cattle breeds as compared to their counterparts kept in normal controlled conditions. Besides, behavioral studies also showed changes in grazing patterns of extensively managed cows with low and high grazing time during day and night, respectively[20]. Higher drinking frequency and increased water intake were reported for various livestock species during summer[21, 23]. Breeds adapted to desert regions compensate for higher water loss during periods of high heat load by concentrating urine[24].

Increased standing and decreased lying time were also reported to be associated with higher ambient temperatures[25-27]. Generally, heat-stressed animals tend to spend more time standing so that they can reorient themselves in different directions to avoid direct solar radiation and ground radiation. Also, the standing position obstructs the conductive heat transfer into the animal body due to the presence of a layer of air adjacent to the skin and also facilitates the dissipation of body heat load to the surroundings by increasing the amount of skin exposed to airflow or wind. However, indigenous Osmanabadi bucks did not show any significant variation for standing time, lying time and urinating frequency, when they were exposed to summer heat stress, indicating their adaptation to hot conditions[21].

Physiological response: The reviewed in Sejian *et al*.[22] on the physiological response that physiologically, ruminants adapt to high heat load through enhanced respiratory and sweating rates[25, 28]. Usually, higher Respiration Rate (RR) and sweating rates are observed when animals are exposed to increasing environmental heat. The respiratory and cutaneous cooling mechanisms directly involve dissipation of the extra heat load in the body by vaporizing more moisture to the surroundings[29, 30]. An increase in RR was reported in various cattle breeds including Angus, Nellore and Sahiwal when they were exposed to high heat load[23]. This shows that even cattle adapted to hot conditions (e.g., Sahiwal) will show a response to the increased environmental heat load.

The study conducted by Leite *et al*.[31], reported greater adaptability of Morada Nova ewes (acclimatized to Brazilian conditions) to hot arid conditions. The ewes were able to maintain normal RR at an ambient temperature of 32°C. An increase in Pulse Rate (PR) and Rectal Temperature (RT) were also reported in farm animals during summer[21, 22]. In addition to this, the greater Rectal Temperature (RT) during summer also confirms the inability of these farm animals to maintain normal body temperature. Daily examination of the indigenous zebu breeds (Gir, Sindhi and Indubrasil) also showed higher magnitude for physiological parameters such as rectal temperature and heart rate during the afternoon (35.9°C)[22, 32]. Similar to this, sheep breeds reared in the Indian semi-arid regions also showed higher PR and RT where the average temperature and humidity during the day was 33.7°C and 54.9%, respectively[22, 33]. The higher Pulse rate enables the stressed animals to dissipate more heat to their surroundings by increasing the blood flow to their body surfaces[21]. Likewise, Osmanabadi goats evolved in the Indian semi-arid regions also showed adapt-ability to heat stress, nutritional stress and combined stress (heat stress+nutritional stress) conditions (temperature, 40°C; humidity, 55%) by altering their physiological variables[21]. Moreover, the report by Katiyatiya *et al*.[34], exposure of ruminants to a hot environment also increased Skin Temperature (ST). Examination of both Nguni and Boran cattle breeds showed higher skin temperature during summer seasons. In the study conducted by Shilja *et al*.[21] and the literature cited by Sejian *et al*.[22], the higher Skin temperature was also recorded in Osmanabadi goats during the Summer Season. This higher Skin temperature could be directly attributed to the vasodilatation of the skin capillary bed to enhance the blood flow to the skin periphery for facilitating heat transfer to the surroundings.

A current study by Sejian *et al*.[22], using Malpura rams reported a significantly lower feed intake and higher water intake in sheep exposed to multiple stressors. Further, significantly higher RR and Rectal Temperature in the multiple stress groups were reported in the same study. Also, Skin temperature and scrotal temperature were significantly higher in the multiple stresses group. It is postulated from these findings that these parameters could be useful biomarkers of the adaptive capacity of Malpura rams. It was observed that scrotal temperature was a better indicator than ST in assessing the impact of multiple stressors[22]. The observed differences between scrotal and Skin temperatures could be attributed to the amount of wool on the body as compared with the scrotum. Furthermore, the scrotum is an important thermoregulatory organ in sheep. Hence, the scrotal temperature has higher significance for assessing the thermo-tolerant capability of sheep. In a similar study in Osmanabadi goats, Shilja *et al*.[21] also reported that Respiration rate, rectal temperature and Skin temperature to be reliable indicators of multiple stressors in goats.

Blood biochemical response: Heat stress results in altered blood biochemical parameters. Heat stress induces an increase in hemoglobin and packed cell volume in cattle and these changes are considered to be a gradual development of adaptive characteristics in cattle[35]. Furthermore, several hormones are involved in controlling the homoeothermic mechanisms of ruminant animals. To adapt to higher ambient temperatures, animals reduce the secretion of thyroid hormones to control metabolic activities and thus the production of body heat. Additionally, cortisol is the primary biochemical marker for heat stress in ruminant livestock. Substantial increases in levels of cortisol during heat stress indicate the stress level of ruminants[36]. Superoxide dismutase and glutathione peroxidase are indicators of oxidative stress in sheep and cattle, particularly during exposure to the excessive heat load. An increase in the concentration of these antioxidants was reported in sheep[37, 38] and dairy cattle[39].

Metabolic response: When animals are exposed to high heat load, the secretion of leptin and adiponectin are up-regulated, where leptin stimulates the hypothalamic axis resulting in a reduction in feed intake while adiponectin changes the feeding behavior by peripheral and central mechanisms. Verma *et al*.[40] attributed this decreased feed intake to the direct effect of increased temperature on the satiety center of the hypothalamus. Changes in the concentration of thyroid hormones in blood reflect the metabolic and nutrient status of the animal.

The difference in the bioactivity of these hormones helps to maintain metabolic balance under stressful conditions, particularly in grazing animals since they are vulnerable to fluctuating environmental changes[41]. It has been established in sheep that the decreased function of the thyroid gland during exposure to high heat load is a metabolic adaptation to reduce metabolic heat production. Increased ambient temperature can also directly affect the hypothalamic-pituitary axis and reduce thyroid-stimulating hormone secretion. Decreased thyroid-stimulating hormone production reduces thyroid gland function and circulating T3 and T4 hormones to reduce metabolic heat production. However, Chauhan *et al*.[42] observed no change in cortisol, T3, or T4 in sheep exposed to the excessive heat load. Metabolic activities are also controlled by several enzymes. Plasma alkaline phosphatase and alanine aminotransferase concentrations generally increase in heat-stressed dairy cows. Serum alanine aminotransferase concentrations also increase in response to heat stress in sheep. The change in alanine aminotransferase and alkaline phosphatase during heat stress are indicators of poor liver function. Thus, both may be good markers in susceptible animals.

Furthermore, a nonesterified fatty acid also plays a crucial role in determining the energy status of livestock. Nonesterified fatty acids have a predominant role in maintaining metabolic activities through its timely mobilization to the liver and peripheral tissues as a source of energy during periods of heat stress. Heat stress results in a considerable decline in nonesterified fatty acid concentrations in lactating cattle[43].

Biological markers: According to Collier *et al*.[44], the genetic differences in thermo-tolerance at the physiological and cellular levels in ruminant livestock have been well documented. Heat tolerance is a quantitative trait. One of the dominant genes identified to impart thermo-tolerance is the slick hair gene which controls the length of hair in cattle. Apart from this, other genes such as ATPase Na+/K+ transporting subunit alpha 1 and ATPase Na+/K+ transporting subunit beta 2, thyroid hormone receptor, fibroblast growth factor and heat shock proteins were found to be associated with heat tolerance in ruminants. The ATPase Na+/K+ transporting subunit alpha 1 gene has also been associated with various heat tolerance variables including respiration rate and rectal temperature in both Tharparkar and Vrindavani cattle breeds suggesting that it may be a good biological marker for thermo-tolerance. Recently, researchers have established a rapid induction of heat shock protein-70 mRNA expression in goats during heat stress exposure confirming its role in heat tolerance[45]. Also, polymorphisms in heat shock protein-90AA1 were found to be associated with heat tolerance in Frieswal cattle[46] and sheep breeds[47]. Increased expression of immune response genes such as a toll-like receptor, toll-like receptor 2/4 and interleukins 2/6 was also documented in heat-stressed Tharparkar cattle. These genes are likely associated with thermo-tolerance[48]. In a recent review, Sejian *et al*.[22] identified respiration rate, rectal temperature, cortisol, plasma heat shock proteins-70, toll-like receptor-2, toll-like receptor-1, toll-like receptor-4, toll-like receptor-5 and heat shock proteins-70 genes to be useful biological markers for quantifying the impact of multiple stressors in both sheep and goats.

Knowledge of the impact of heat stress on the various adaptive responses provides a clear insight into future ruminant livestock production. The various biological markers identified for the heat stress condition may also help researchers develop climate-resilient breeds based on both phenotypic and genotypic markers involving morphological, behavioral, physiological, cellular and molecular processes. Also, combining the variously identified biomarkers may help to look beyond thermo-tolerance in livestock and may go a long way to identify a breed or breeds with superior thermo-tolerance for optimum productivity. Therefore, with the advancement in assessing the various mechanisms associated with thermo-tolerance, it is possible to secure and sustain future ruminant livestock production by promoting the welfare and favoring survival in a specific environment.

Effect of stress on animal productivity: The impact of stress on growth, production, reproduction and disease outcome in farm animals has been studied by various researchers. A concise review of the effects of stress on these parameters and the underlying mechanisms involved are briefly presented. According to the reviewed by Girma and Gebremariam[49] on the effect of Stress on production and reproduction of Dairy Cattle and reported that Stress affects the reproductive performance of both males and females. In male’s quantity and quality of the sperm and females fertility percentage, fertility and embryo quality declines. Moreover, the productive performance of cattle like milk production and growth of cattle is also affected by stress factors. Hence, managing the effect of stress factors is aimed at alleviating rather than eliminating the challenges on animals production and providing shelters, insulation in the form of bedding, proper feeding and reduction of the dry matter daily intake, reduction of rumen fermentation activity, reduction of physical activity and direct cooling of animal is needed to alter stress.

Growth and production performance: The main objective in animal production is maximum growth through the effective use of feed and other resources. An increase in size can be termed as animal growth, in simplest terms. Animal’s skeletal dimensions and its composition changes when animal grow from conception to maturity. The growth and production performances of animals are adversely affected by different kinds of stressors. Increased levels of glucocorticoids in response to stress stimulate hypothalamic secretion of somatostatin which inhibits Growth Hormone (GH) secretion from the anterior pituitary. The growth of animals is affected by these stress hormones. Transportation stress in animals has been established to cause a reduction in their body weight[50].

During transportation, physiological alterations such as electrolyte imbalance increased respiration rate and heart rate, dehydration, energy deficit and related catabolism have been reported[51]. Besides transportation, heat stress has also been scientifically established to produce a negative impact on the growth performance of animals. Different species, breeds and individuals depending upon their physiological states have comfort zones of temperature tolerance. Beyond these limits, the animals require extra energy for thermoregulation. Therefore, less energy is available for growth and production performances. Heat associated with high humidity or drought remains the most stressful condition for animals. In heat-stressed animals, there is reduced feed intake which harms growth and milk production. Heat stress in lactating cows leads to a decline in milk production and protein content[52]. The fall in milk yield in a hot environment is higher for older and more productive animals especially at the peak of lactation. The animals experiencing cold stress also have reduced milk yield but the decline is less when compared to heat-stressed animals. High ambient air temperature and solar radiation have been shown to harm dry matter intake, average daily gain, carcass weight and fat thickness in beef cattle[53]. The decline in feed intake ranging from 40-60% in 15-month-old buffaloes by variation of temperature and humidity has been reported.

Milk production traits in small ruminants have also been reported to have a negative correlation with temperature or relative humidity. Different breeds of sheep have been reported to have variable tolerance for temperature and humidity[54]. Solar radiations have a lesser effect on milk yield but a greater effect on yield of casein, fat and clot firmness in the milk of Comisana ewes. High air temperature also affects the milk yield and milk components in goats. Lactating goats deprived of water during heat stress activate an efficient mechanism for reducing water loss in urine, milk and by evaporation, to maintain milk production for a longer time. In heat-stressed pigs due to reduced feed intake the milk yield of the sow decreases, hence growth, viability and survival of piglets also decline[55]. In high ambient air temperature, the heavier pigs reduce more appetite and growth. Because protein deposits require more energy than fat deposits, the carcasses are leaner at slaughter. In a study, decreased growth, carcass lipid quality and bacon quality in pigs housed at temperatures above the thermoneutral zone have been observed[56]. Overcrowding further aggravates the condition whereas increasing the space allocation for housing may ameliorate the negative effects of heat stress. Multiple concurrent stressors like high temperature, high stocking density and regrouping affect the growth performance of pigs additively.

Environmental temperatures above 30°C cause a reduction in feed intake, body weight, carcass weight, carcass protein and muscle calorie content and high mortality in broiler chickens. In hens, there is a reduction in body weight and feed consumption due to heat stress. Egg production, egg weight, shell weight and shell thickness are considerably compromised by heat exposure[57].

Effect of stress on animal reproduction: Stress has been reported to influence animal reproduction adversely. The impact of stress on reproduction depends on the type of stress, genetic predisposition of the animals, timing and duration of the stress. Stress conditions such as infection, strenuous exercise and malnutrition have been reported to predispose to various reproductive pathologies like infertility or sub-fertility, defective oocytes and consequent reduction in conception rates. Reproductive processes like an expression of sexual behavior, ovulation and embryo implantation are controlled by the neuroendocrine system. The alterations in neuroendocrine responses as a result of stress are likely to influence these processes.

According to reviewed by Kumar *et al*.[2], stress stimulates the hypothalamus, pituitary gland and gonads directly to affect Gonadotropin-Releasing Hormone (GnRH) secretion into the hypophyseal portal blood. The hypothalamic-pituitary-adrenal axis is stimulated and produces Corticotrophin-Releasing Factor (CRF) and arginine vasopressin. Corticotropin-Releasing Factor (CRF) interacts with GnRH-producing neurons, probably through an opioidergic pathway, suppressing gonadotropin secretion. Leptin and adiponectin also provide feedback to the hypothalamus for GnRH release. The corticotrophs produce neuropeptides an Adrenocorticotrophic Hormone (ACTH), beta-endorphin and alpha-melanocyte-stimulating hormone due to stress impact. ACTH acts on the cortex of the adrenal glands to stimulate the synthesis and secretion of glucocorticoids. Glucocorticoid feedback action on the brain also suppresses overactivity of the Hypothalamic-Pituitary-Adrenal (HPA) axis. Besides, glucocorticoid secretion is also believed to contribute to stress-induced gonadal suppression by central actions on the pituitary or hypothalamus. The sympathoadrenal system consists of the sympathetic nervous system and the adrenal medulla. It is activated in response to stress and produces catecholamines (adrenalin, noradrenaline and dopamine). Hormones that comprise components of the HPA axis, such as CRH, arginine vasopressin, ACTH and glucocorticoids have all been shown to inhibit GnRH/gonadotropin secretion at the hypothalamic and/or pituitary levels. CRH inhibits GnRH release in hypophyseal portal blood or GnRH pulse generator activity. Arginine vasopressin and ACTH are also reported to inhibit LH secretion by decreasing responsiveness of the pituitary to GnRH as well as decreasing GnRH release.

The effects of heat stress on the reproduction of dairy cattle have been studied extensively. Heat stress in the summer months lowers the conception rate of lactating dairy cows from 40-60-10-20%[58]. It hurts the anterior pituitary, preovulatory follicle, corpus luteum, embryo developments and endometrium resulting in low fertility and loss of the fetus. Estrus behavior in cattle and buffaloes is affected by heat stress in summers resulting in silent estrus or reduced estrus intensity and decreased duration. Heat stress damages ovarian follicles and causes a decrease in estradiol synthesis. This decrease in estradiol synthesis could influence the expression of estrus, ovulation and the corpus luteum. It has been demonstrated that dairy cows in the summer had approximately one-half the number of mounts per estrus compared to dairy cows in the winter.

Stress results in a disturbance of spermatogenesis decreased sperm fertility parameters and disturbed folliculogenesis. Catecholamines interfere with the transport of gametes and decrease blood flow. Early embryonic loss in livestock is common due to stress. Prenatal maternal stress results in an increased incidence of spontaneous abortion, preterm delivery and low birth weight. Maternal prenatal stress may induce over-activity and/or dysregulation of the HPA-system in the offspring[59, 60].

Cattle, sheep in heat stress exhibit reduced uterine and umbilical blood flows, resulting in reduced fetal oxygen. Heat stress has also been shown to have a deleterious effect on estrus incidences, estrus intensity and embryo production in ewes[61]. The service period is increased because of stress arising due to milk fever or lameness in dairy cows. Stress due to transportation in dairy cattle reduces LH secretion in response to exogenous GnRH. In sheep, restraint and confinement enhances plasma cortisol concentrations and simultaneously decrease the pituitary's response to GnRH administration. Conditions, in which nutritional status is suboptimal such as eating disorders, exercise-induced amenorrhea and functional hypothalamic amenorrhea, are associated with low serum leptin levels[62]. GnRH pulse is highly affected by weight loss, decreased energy availability, altered body fat ratio. Although short-term fasting of adult cows in healthy body condition does not affect LH pulse frequency. Short-term fasting of peripubertal heifers leads to significant reductions in leptin gene expression and circulating leptin, along with a decrease in LH pulse frequency[63].

Strategies for alleviating stress in farm animals

Breeding management: As animals exhibit lesser heat symptoms during heat stress zones as compared to thermal comfort periods, it is necessary to adopt a good heat detection program to detect cows with marginal heat symptoms. It is always advisable to continue AI breeding instead of using bulls because in natural breeding both bull and cows suffer infertility due to summer stress. Genetic selection of heat-tolerant animals and inclusion of heat tolerance as a trait in the selection program will be a boon to the farms.

Cooling systems in the farm for heat stress: Fans in combination with a water sprinkling facility provide the best cooling option. Excessive sprinkling should never be practiced as it can result in wet bedding making animals prone to mastitis and other diseases. The farm should be well ventilated. Provide a ventilation system that controls body temperature, implement water sprinklers. Animal protection against solar radiation, directly and indirectly, through shadows or appropriate ceilings, provide shade in feeding and drinking, to increase feed intake in animals with heat stress, provide water sprays, provide animals, spray baths, in the hottest part of the day, try to have animals with white fur as they are the most easily absorb heat and therefore are less sensitive to heat stress, develop genetically adapted in animals, as they may be less sensitive to heat stress, implementation of frozen embryos, insemination with frozen semen in the less hot time.

Feeding management: Heat stressed animals are more likely to have lower reproductive and productive performance. Feeding high-quality forages and balanced rations will decrease some of the effects of heat stress and will boost the performance of the animals. Some nutritional management tips to manage heat stress are: Provide high quality feeds like total mixed rations, increase the frequency of feedings; feed during cooler times of the day, keep feed fresh as much as possible, provide high-quality forage and adequate fiber, use bypass proteins can enhance the milk yield and protein content and intake of sufficient cool water is probably the most important strategy for animals to undertake during heat stress. Balancing diets properly, providing the energy needed to offset declining intake presented, reduce your intake of fiber and protein and increase energy. Several extensive reviews of nutritional strategies for managing heat-stress dairy cows, poultry and pigs[55] have been published. Various dietary approaches or feeding strategies have been used to alleviate the adverse effect of heat stress with varying degrees of success. They aim to maintain water balance, nutrients and electrolytes intake and/or to satisfy the special needs during heat stress such as vitamins and minerals.

Changes in macronutrients composition: The depressed feed intake in hot weather is commonly considered as an adaptation to reduce metabolic heat production. Heat increment because of the metabolic utilization of Crude Proteins (CPs) or fiber is higher than for starch or fat. The higher heat increment of CP is partly related to the excess of Amino Acids (AAs) for urea synthesis and a higher protein turnover. The energy losses associated with the metabolic utilization of digestible ?ber are mainly related to the losses of combustible gases and heat arising from fermentation and during the production of ATP from the oxidation of short-chain fatty acids which is less efficient compared with ATP gains from the oxidation of glucose. From that, it has been suggested that low-CP or fiber diets should attenuate the depressed intake associated with heat stress. Moreover, the reduction in dietary fiber reduces the bulk density of the diet and then would encourage intake.

Providing natural or artificial shade area: Plantation around the farm will help in alleviating heat load from the animals. But, in today's commercial dairy industry, it is not always practicable. Therefore, the provision of an artificial shade area by a shade cloth or a naturally well-ventilated structure with open sidewalls can keep the animals away from direct solar radiation. Provide free areas in the Production Unit and shaded, provide the required area per animal, for comfort, bathing females before service and 3-5 days, breed or service in less hot periods, Implement estrus synchronization programs, to schedule inseminations or services, do not isolate females long before artificial insemination or service.

Selection of heat-tolerant animals: Genetic Selection of animals based on specific molecular genetic markers for heat tolerance will be a boon to alleviate heat stress in cattle and buffaloes by identifying the heat-tolerant animals[64].

CONCLUSION

Stress is a key limiting factor to efficient animal production and negatively impacts the health and productivity of livestock during all lifecycle stages. Although, stress is a normal experience for livestock and not necessarily harmful when animals can cope, there is a potential for distress and therefore compromised animal welfare when animals cannot adapt. Specifically, HS undermines substantial advances made by the global animal agriculture industries and jeopardizes animal well-being and the efficient production of high-quality animal protein. Traditionally, HS research has focused on the postnatal production consequences (i.e., Body Weight (BW), Average Daily Gain (ADG), milk production) of heat stress, however, recent reports indicate that prenatal HS may be partially responsible for reduced postnatal performance. Therefore, as the researcher's knowledge of the negative impacts of heat stress on livestock well-being and performance increase, so will the need for research demonstrating production practices that not only increase animal performance but also improve animal welfare and promote heat stress recovery. Heat stress can challenge the reproductive and production potential of the animals. Implementing proper breeding programs, cooling strategies at the farm with better feeding programs can help to minimize some of the negative effects of heat stress[65].

The future research needs for ameliorating heat stress in livestock are to identify strategies for developing and monitoring appropriate measures of heat stress; assess genetic components including genomics and proteomics of heat stress in livestock and develop alternative management practices to reduce heat stress and improve animal well-being and performance. Special emphasis must be given to study the influence of climate change on epigenetic changes to understand the differences in adaptive changes that are evolved over a generation which may help to understand the hidden intricacies of molecular and cellular mechanisms of livestock adaptation. Further studies are also needed in identifying ruminant species-specific biological markers for different environmental stresses that arise as a result of climate change and such markers should be included in the existing breeding programs to develop climate-resilient animals through marker-assisted selection breeding program. Besides, such breeding approaches must be a blend of adaptive, productive and low methane emission traits to evolve a breed that can simultaneously withstand climatic stresses, sustain production and emit low methane. These are the efforts that are needed in near future to sustain livestock production to ensure global food security in the changing climate scenario[66].

REFERENCES

01. Etim, N.N., M.E. Williams, E.I. Evans and E.E.A. Offiong, 2013. Physiological and behavioural responses of farm animals to stress: Implications to animal productivity. Am. J. Adv. Agric. Res., 1: 53-61.
02. Kumar, B., A. Manuja and P. Aich, 2012. Stress and its impact on farm animals. Front Biosci., E4: 1759-1767.
03. Curtis, A.K., B. Scharf, P.A. Eichen and D.E. Spiers, 2017. Relationships between ambient conditions, thermal status and feed intake of cattle during summer heat stress with access to shade. J. Therm. Boil., 63: 104-111.
04. Keown, F.J. and R.G. Grant, 1997. How to reduce heat stress in dairy cattle. http://www.unl.edu/IANR/PUBS/extnpubs/dairy/1063 html.
05. Gebregeziabhear, E. and N. Ameha, 2015. The effect of stress on productivity of animals: A review. J. Biol. Agric. Health, 5: 14-22.
06. Hemsworth, P. and G. Coleman, 2011. Effects of stockperson behaviour on animal welfare and productivity. Proceedings of the 4th Boerhringer Ingelheim Expert Forum on Farm Animal Wellbeing, May 27th 2011, Seville, Spain, pp: 21-26.
07. Rushton, J., 2009. The Economics of Animal Health and Production. CABI, Wallingford, UK., ISBN: 978-1-84593-194-0, Pages: 364.
08. FAO., 2009. The State of Food and Agriculture 2009: Livestock in the Balance. Food and Agriculture Organization of the United Nations, Rome, Italy, ISBN-13: 9789251062159, Pages: 166.
09. Lovejoy, D.A. and D. Barsyte, 2011. Sex, Stress and Reproductive Success. John Wiley & Sons, Ltd, New York, USA.,.
10. Romero, L.M. and J.C. Wingfield, 2016. Tempests, Poxes, Predators and People: Stress in Wild Animals and how They Cope. Oxford University Press, England, UK.,.

11. Thamo, T., D. Addai, D.J. Pannell, M.J. Robertson, D.T. Thomas and J.M. Young, 2017. Climate change impacts and farm-level adaptation: Economic analysis of a mixed cropping-livestock system. Agric. Syst., 150: 99-108.
12. Mika, A., G.J. Mazur, A.N. Hoffman, J.S. Talboom, H.A. Bimonte-Nelson, F. Sanabria and C.D. Conrad, 2012. Chronic stress impairs prefrontal cortex-dependent response inhibition and spatial working memory. Behav. Neurosci., 126: 605-619.
13. Beery, A.K. and D. Kaufer, 2015. Stress, social behavior and resilience: Insights from rodents. Neurobiol. Stress, 1: 16-127.
14. Sejian, V., R. Bhatta, J.B. Gaughan, F.R. Dunshea and N. Lacetera, 2018b. Adaptation of animals to heat stress. Anim., 12: 431-444.
15. McManus, C., G.R. Paludo, H. Louvandini, R. Gugel, L.C.B. Sasaki and S.R. Paiva, 2009. Heat tolerance in Brazilian sheep: Physiological and blood parameters. Trop. Anim. Health Prod., 41: 95-101.
16. Mahgoub, O., I.T. Kadim, A. Al-Dhahab, R.B. Bello, I.S. Al-Amri, A.A.A. Ali and S. Khalaf, 2010. An assessment of Omani native sheep fiber production and quality characteristics. J. Agricu. Mar. Sci., 15: 9-14.
17. Gootwine, E., 2011. Mini review: Breeding Awassi and Assaf sheep for diverse management conditions. Trop. Anim. Health Prod., 43: 1289-1296.
18. Jian, W., Y. Ke and L. Cheng, 2015. Physiological responses and lactation to cutaneous evaporative heat loss in *Bos indicus*, *Bos taurus* and their crossbreds. Asian-Australas J. Anim. Sci., 28: 1558-1564.
19. Brito, L.F., A.E. Silva, R.T. Barbosa and J.P. Kastelic, 2004. Testicular thermoregulation in Bos indicus, crossbred and Bos taurus bulls: Relationship with scrotal, testicular vascular cone and testicular morphology and effects on semen quality and sperm production. Theriogenology, 61: 511-528.
20. Collier, R.J., B.J. Renquist and Y. Xiao, 2017. A 100-year review: Stress physiology including heat stress. J. Dairy Sci., 100: 10367-10380.
21. Shilja, S., V. Sejian, M. Bagath, A. Mech and C.G. David *et al*., 2016. Adaptive capability as indicated by behavioral and physiological responses, plasma HSP70 level and PBMC HSP70 mRNA expression in Osmanabadi goats subjected to combined (heat and nutritional) stressors. Int. J. Biometeorol., 60: 1311-1323.
22. Sejian, V., D. Kumar and S.M.K. Naqvi, 2018a. Physiological rhythmicity in Malpura ewes to adapt to cold stress in a semi-arid tropical environment. Biol. Rhythm Res., 49: 215-225.
23. Valente, E.E.L., M.L. Chizzotti, C.V.R. de Oliveira, M.C. Galvao, S.S. Domingues, A.C. Rodrigues and M.M. Ladeira, 2015. Intake, physiological parameters and behavior of Angus and Nellore bulls subjected to heat stress. Semina: Ciencias Agrarias, 36: 4565-4574.
24. Chedid, M., L.S. Jaber, S. Giger-Reverdin, C. Duvaux-Ponter and S.K. Hamadeh, 2014. Water stress in sheep raised under arid conditions. Can. J. Anim. Sci., 94: 243-257.
25. Silanikove, N., 2000. The physiological basis of adaptation in goats to harsh environments. Small Rumin. Res., 35: 181-193.
26. Darcan, N., F. Cedden and S. Cankaya, 2008. Spraying effects on some physiological and behavioural traits of goats in a subtropical climate. Ital. J. Anim. Sci., 7: 77-85.
27. Provolo, G. and E. Riva, 2009. One year study of lying and standing behaviour of dairy cows in a frestall barn in Italy. J. Agric. Eng., 40: 27-33.
28. Marai, I.F.M., A.A. El-Darawany, A. Fadiel and M.A.M. Abdel-Hafez, 2007. Physiological traits as affected by heat stress in sheep-A review. Small Rumin. Res., 7: 1-12.
29. Kadzere, C.T., M.R. Murphy, N. Silanikove and E. Maltz, 2002. Heat stress in lactating dairy cows: A review. Livest. Prod. Sci., 77: 59-91.
30. Berman, A., 2006. Extending the potential of evaporative cooling for heat-stress relief. J. Dairy Sci., 89: 3817-3825.
31. Leite, J.H.G.M., D.A.E. Facanha, W.P. Costa, D.F. Chaves, M.M. Guilhermino, W.S.T. Silva and L.A. Bermejo, 2018. Thermoregulatory responses related to coat traits of Brazilian native ewes: An adaptive approach. J. Appl. Anim. Res., 46: 353-359.
32. Cardoso, C.C., V. Peripolli, S.A. Amador, E.G. Brandao and G.I.F. Esteves *et al*., 2015. Physiological and thermographic response to heat stress in zebu cattle. Livest. Sci., 182: 83-92.
33. Rathwa, S.D., A.A. Vasava, M.M. Pathan, S.P. Madhira, Y.G. Patel and A.M. Pande, 2017. Effect of season on physiological, biochemical, hormonal and oxidative stress parameters of indigenous sheep. Vete. World, 10: 650-654.
34. Katiyatiya, C.L.F., G. Bradley and V. Muchenje, 2017. Thermotolerance, health profile and cellular expression of *HSP90AB1* in Nguni and Boran cows raised on natural pastures under tropical conditions. J. Therm. Biol., 69: 85-94.
35. Mazzullo, G., C. Rifici, G. Caccamo, M. Rizzo and G. Piccione, 2014. Effect of different environmental conditions on some haematological parameters in cow. Ann. Anim. Sci., 14: 947-954.

36. Sivakumar, A.V.N., G. Singh and V.P. Varshney, 2010. Antioxidants supplementation on acid base balance during heat stress in goats. Asian-Australian J. Anim. Sci., 23: 1462-1468.
37. Chandra, G. and A. Aggarwal, 2009. Effect of DL-tocopherol acetate on calving induced oxidative stress in periparturient crossbred cows during summer and winter seasons. Indian J. Anim. Nut., 26: 204-210.
38. Chaudhary, S.S., V.K. Singh, R.C. Upadhyay, G. Puri, A.B. Odedara and P.A. Patel, 2015. Evaluation of physiological and biochemical responses in different seasons in Surti buffaloes. Vet. World, 8: 727-731.
39. Bernabucci, U., B. Ronchi, N. Lacetera and A. Nardone, 2002. Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. J. Dairy Sci., 85: 2173-2179.
40. Verma, D.N., S.N. Lal, S.P. Singh and O. Parkash, 2000. Effect of season on biological responses and productivity of buffalo. Int. J. Anim. Sci., 152: 237-244.
41. Todini, L., 2007. Thyroid hormones in small ruminants: Effects of endogenous, environmental and nutritional factors. Animal, 1: 997-1008.
42. Chauhan, S.S., P. Celi, B.J. Leury, I.J. Clarke and F.R. Dunshea, 2014. Dietary antioxidants at supranutritional doses improve oxidative status and reduce the negative effects of heat stress in sheep. J. Anim. Sci., 92: 3364-3374.
43. Baumgard, L.H. and R.P. Jr. Rhoads, 2013. Effects of heat stress on postabsorptive metabolism and energetics. Annu. Rev. Anim. Biosci., 1: 311-337.
44. Collier, R.J., G. Macko, A.R. Macko and K.S. Roy, 2012. Genes Involved in the Thermal Tolerance of Livestock. In: Environmental Strsse and Amelioration in Livestock Production, Sejian, V., S.M.K. Naqvi, T. Ezeji, J. Lakritz and R. Lal (Eds.)., Springer, New York, USA., pp: 379-410.
45. Aleena, J., V. Sejian, M. Bagath, G. Krishnan, V. Beena and R. Bhatta, 2018. Resilience of three indigenous goat breeds to heat stress based on phenotypic traits and PBMC HSP70 expression. Int. J. Biometeorol., 62: 1995-2005.
46. Deb, R., B. Sajjanar, U. Singh, S. Kumar and M.P. Brahmane *et al*., 2013. Promoter variants at AP2 box region of Hsp70.1 affect thermal stress response and milk production traits in Frieswal cross bred cattle. Gene, 532: 230-235.
47. Marcos-Carcavilla, A., M. Mutikainen, C. Gonzalez, J.H. Calvo and J. Kantanen *et al*., 2010. A SNP in the *HSP90AA1* gene 5 flanking region is associated with the adaptation to differential thermal conditions in the ovine species. Cell Stress Chaperones, Vol. 15, 10.1007/s12192-009-0123-z
48. Bharati, J., S.S. Dangi, S.R. Mishra, V.S. Chouhan and V. Verma *et al*., 2017. Expression analysis of toll like receptors and interleukins in Tharparkar cattle during acclimation to heat stress exposure. J. Therm. Biol., 65: 48-56.
49. Girma, F. and B. Gebremariam, 2019. Review on effect of stress on production and reproduction of dairy cattle. J. Sci. Innovative Res., 8: 29-32.
50. Kannan, G., T.H. Terrill, B. Kouakou, S. Gelaye and E.A. Amoah, 2002. Simulated preslaughter holding and isolation effects on stress responses and live weight shrinkage in meat goats. J. Anim. Sci., 80: 1771-1780.
51. Das, K.S., B.B. Srivastava and N. Das, 2001. Standing orientation and behaviour of goats during short-haul road transportation. Small Ruminant Res., 41: 91-94.
52. Ravagnolo, O. and I. Misztal, 2000. Genetic component of heat stress in dairy cattle, parameter estimation. J. Dairy Sci., 82 : 126-230.
53. Mitlohner, F.M., J.L. Morrow, J.W. Dailey, S.C. Wilson, M.L. Galyean, M.F Miller and J.J. McGlone, 2001. Shade and water misting effects on behavior, physiology, performance and carcass traits of heat-stressed feedlot cattle. J. Anim. Sci., 79: 2327-2335.
54. Finocchiaro, R., J.B.C.H.M. van Kaam, B. Portolano and I. Misztal, 2005. Effect of heat stress on production of mediterranean dairy sheep. J. Dairy Sci., 88: 1855-1864.
55. Renaudeau, D., N. Mandonnet, M.T. Boichard, J. Noblet and J.P. Bidanel, 2004. [Mitigating the effects of heat on pig performance: The genetic pathway (In French)]. Prod. Anim., 17: 93-108.
56. White, H.M., B.T. Richert, A.P. Schinckel, J.R. Burgess, S.S. Donkin and M.A. Latour, 2008. Effects of temperature stress on growth performance and bacon quality in grow-finish pigs housed at two densities. J. Anim. Sci., 86: 1789-1798.
57. Mashaly, M.M., G.L. Hendricks, M.A. Kalama, A.E. Gehad, A.O. Abbas and P.H. Patterson, 2004. Effect of heat stress on production parameters and immune responses of commercial laying hens. Poult. Sci., 83: 889-894.
58. Wolfenson, D., Z. Roth and R. Meidan, 2000. Impaired reproduction in heat-stressed cattle: Basic and applied aspects. Anim. Reprod. Sci., 60: 535-547.
59. Mulder, E.J., P.G. Robles de Medina, A.C. Huizink, B.R. van den Bergh, J.K. Buitelaar and G.H. Visser, 2002. Prenatal maternal stress: Effects on pregnancy and the (unborn) child. Early Hum. Dev., 70: 3-14.
60. Breen, K.M., A.E. Oakley, A.V. Pytiak, A.J. Tilbrook, E.R. Wagenmaker and F.J. Karsch, 2007. Does cortisol acting via the type II glucocorticoid receptor mediate suppression of pulsatile luteinizing hormone secretion in response to psychosocial stress?. Endocrinology, 148: 1882-1890.

61. Maurya, V.P., S.M.K. Naqvi, A. Joshi, J.P. Mittal and V.K. Singh, 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.
62. Basdevant, A. and C. Ciangura, 2007. Leptin: From gene to energy balance. Exp. Clin. Endocrinol Diabetes, 115: 423-427.
63. Williams, G.L., M. Amstalden, M.R. Garcia, R.L. Stanko, S.E. Nizielski, C.D. Morrison and D.H. Keisler, 2002. Leptin and its role in the central regulation of reproduction in cattle. Domestic. Anim. Endocrinol., 23: 339-349.
64. Kaliber, M., N. Koluman and N. Silanikove, 2016. Physiological and behavioral basis for the successful adaptation of goats to severe water restriction under hot environmental conditions. Animal, 10: 82-88.
65. Polsky, L. and M.A.G. von Keyserlingk, 2017. Effects of heat stress on dairy cattle welfare. J. Dairy Sci., 100: 8645-8657.
66. Spiers, D.E., J.N. Spain, J.D. Sampson and R.P. Rhoads, 2004. Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. J. Thermal Biol., 29: 759-764.