Ann. Anim. Sci., Vol. 17, No. 1 (2017) 59–88 *DOI: 10.1515/aoas-2016-0068*

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TOWARDS HEAT STRESS MANAGEMENT IN SMALL RUMINANTS – A REVIEW

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Abstract

Small ruminants (sheep and goats) play a predominant role in the economy of million people, and have provided meat, milk, skin, wool and fiber for centuries. Animals undergo various kinds of stressors, i.e. physical, nutritional, chemical, psychological and heat stress (HS). Among all, HS is the most concerning at present in the ever-changing climatic scenario. Climate change is the most serious long-term challenge faced by small ruminants' owners worldwide. HS results in decreased growth, reproduction, production, milk quantity and quality, as well as natural immunity, making animals more vulnerable to diseases, and even death. Thus, HS results in great economic losses, emphasizing the necessity to objectively assess animal welfare. The increasing demand for animal products paralleled by the frequent hot climate is a serious threat for the agriculture sector. The ability of sheep and goats to cope with HS without harming their welfare and productive performance has been often overrated. To date, little attention has been paid to comprehensive detailed data on the adverse effect of HS on sheep and goats. Therefore, this review discusses in detail the sheep and goats' behavioral, physiological, molecular/cellular, hematological, biochemical and immunological responses under HS conditions. In addition, this review also presents the adverse effects of HS on reproduction and fertility, milk quantity and quality, feed intake, and water consumption of sheep and goats. Finally, this review suggests various methods for HS alleviation. In conclusion, HS impairs productivity and well-being in sheep and goats. The improved understanding of the impact of HS on small ruminants will help in developing management techniques to alleviate HS and highlighting the need for future researches on HS in sheep and goats.

Key words: small ruminants, heat stress, management, harsh environment

The demand for livestock (including small ruminants) products has been largely driven by the rapid growth of the human population, increases in income and urbanization (Thornton, 2010). The livestock sector is increasingly organized in long market chains that employ more than 1.3 billion people globally and directly support the livelihoods of 600 million poor smallholder farmers in the developing world (Thornton, 2010). Globally, small ruminants play an important role in the economy of millions of people who earn their livelihood by rearing these animals in different climatic conditions (Ben Salem, 2010; Silanikove et al., 2010; Gupta et al., 2013).

Sheep and goats are among the most successful animals with a wide geographical distribution extending from Europe to Siberia and from Alaska to South America, playing an important role in the agricultural revolution and advance of human civilization. The goats are thought to have been domesticated around 10,000 years ago (Zeder, 2008; Dwyer, 2009), and 9,500 years ago for sheep (Zeder, 2008) in the so-called 'Fertile Crescent' of the Middle East (Silanikove et al., 2015). Both animal species play a predominant role in the sustenance of the livelihoods of impoverished families, especially in rural areas (Ben Salem and Smith, 2008; Okoruwa, 2014). Sheep and goats owe their popularity to their multi-purpose ability to provide meat, milk, skin, offal, horn, dung for fuel, wool, and fiber (Dwyer, 2009; Ben Salem, 2010). Also, these animals are well adapted under different geographical and environmental conditions including extreme and harsh climates (Al-Haidary et al., 2012; Banerjee et al., 2014), and perform better than other domesticated ruminants. However, goats tend to tolerate heat better than sheep (Silanikove, 2000 a; Jakper and Kojo, 2014). Worldwide, there are more than 1,000 sheep and 600 goat breeds (Dwyer, 2009), and these breeds differ in their capacity to overcome climatic conditions. For example, Najdi (the principal native sheep breed in the central region of Saudi Arabia) is less drought tolerant than the Awassi breed (Alamer and Al-Hozab, 2004). Goats with loose skin and floppy ears are more heat tolerant than other goats (Jakper and Kojo, 2014). Angora goats have a decreased ability to respond to heat stress (HS) as compared to sheep and other breeds of goats (Jakper and Kojo, 2014). However, despite their extreme tolerance, the productivity of these animals often declines due to HS (Banerjee et al., 2014). Therefore, proper breed selection is a very valuable tool for sustaining animal production under an increasingly challenging environment (Silanikove, 1992). Nevertheless, importing high-producing breeds from temperate to desert and tropical areas does not always work well because of poor adaption to HS. Crossbreeding is a common strategy to resolve this problem.

Stress is described as the cumulative detrimental effect of a variety of factors on the health and performance of animals, or also described as the magnitude of forces external to the body which tend to displace its systems from their ground state (Silanikove, 2000 a). Animals undergo various kinds of stressors, i.e. physical, nutritional, chemical, psychological and HS. Among all, HS is the most concerning issue nowadays in the ever-changing climatic scenario (Silanikove and Koluman, 2015), and it is one of the most important stressors especially in the tropical, subtropical (Marai et al., 2007; Nardone et al., 2010), arid (Silanikove, 1992), and semiarid (Silanikove, 2000 a; Al-Dawood, 2015) regions of the world. HS is the perceived discomfort and physiological strain associated with an exposure to an extreme and hot environment (Gupta et al., 2013).

Climate change is the most serious long-term challenge faced by small ruminants' owners in much of the world, as it impacts animals' production and health (Silanikove and Koluman, 2015). Environmental factors such as ambient temperature, solar radiation and relative humidity have direct and indirect effects on animals (Collier et al., 1982). High ambient temperature is the major concern that challenges the animal's ability to maintain energy, thermal, water, hormonal and mineral balance (Silanikove, 1992). The intergovernmental panel on climate change reported that the period from 1983 to 2012 was the warmest 30-year period of the last 1,400 years in the Northern Hemisphere (IPCC, 2014 a). They predict that by the year 2100, the increase in global surface temperature may be 3.7–4.8°C (IPCC, 2014 b). It is expected 20–30% of livestock to be at risk of extinction (FAO, 2007) due to changes in weather and climate events. There is evidence that climate change, especially elevated temperature, has already changed the overall abundance, seasonality and spatial spread of farmed small ruminants (Van Dijk et al., 2010). Animal welfare outcomes show that HS compromises animal welfare and it is commonly stated that HS causes mortality in both sheep and goats under inappropriate transport conditions (Caulfield et al., 2014). However, unlike the situation in cows (St-Pierre et al., 2003) there are no reports so far on mortality due to HS under conventional farming conditions, even in those raised in areas exposed to extreme HS (e.g., in Saudi Arabia).

HS influences ovarian function and embryonic development which results in decreased fertility (Gupta et al., 2013; Kandemir et al., 2013). HS redistributes the body resources including protein and energy at the cost of decreased growth, reproduction, production and health of animals (Gupta et al., 2013). In addition, HS reduces milk yield and quality (Salama et al., 2012). The general homeostatic responses to HS in sheep and goats include raised respiration rate (Mortola and Frappell, 2000), body temperature (Marai et al., 2000) and water consumption (Gupta et al., 2013; Kandemir et al., 2013), decreased feed intake (Marai et al., 2000; Facanha et al., 2012 b), and dry matter intake (Caulfield et al., 2014). Also, HS lowers natural immunity, making animals more vulnerable to diseases (Schaefer et al., 1997). Collapse and even death can result if the heat load experienced by the animal becomes excessive (Barnes et al., 2004).

Objectives

The increasing demand for small ruminants' products owing to urbanization, growing human populations and developing economies, paralleled by frequent hot climate are serious threats for the agriculture sector. In recent years, interest in welfare of small ruminants has rapidly escalated. One of the reasons for this interest is due to the adverse effects of HS which increases morbidity and mortality rates, affects reproductive performance of animals, and results in great economic losses, emphasizing the necessity to objectively assess the welfare of the animals. Environmental issues cause major stress to the small ruminant industry. The concern for meteorological elements in recent years is due to the fact that they are not constant, but change continuously. The identification of heat-stressed animals and understanding the biological mechanisms by which HS reduces milk production and reproductive functions is critical for developing novel approaches to maintain production or minimize the reduction in productivity during HS conditions.

Since sheep and goats are considered very rustic animals, their ability to cope with hot environmental conditions, without harming their welfare and productive performance, has been often overrated (Al-Dawood, 2015). In addition, the diffusion of extensive husbandry of sheep and goats has led to the belief that they do not need any welfare assessment (Kandemir et al., 2013). Knowledge on how HS can adversely affect animals' performance and health is of vital importance. Currently, there are many reasons that justify the urgent need to develop sustainable strategies to improve the efficiency of production systems of small ruminants in different agro-ecological zones. To date and to the best of our knowledge, little attention has been paid to comprehensive detailed data on the adverse effects of HS on small ruminants. Therefore, the present review discusses in detail the sheep and goats' behavioral, physiological, molecular, hematological, biochemical and immunological responses under HS conditions. In addition, the adverse effects of HS on quantity and quality of milk, quality of meat, feed intake, water consumption, animals' reproduction and fertility are thoroughly presented. Furthermore, this review also discusses various methods for HS alleviation. The improved understanding of the impact of HS on small ruminants will help in developing management techniques to alleviate HS in animals and highlighting the need for future research on HS in small ruminants.

Several strategies were used to capture the literature related to the review topic: (1) Similar terms to those used for the peer-review literature were applied in the internet search engines (Google and GoogleScholar) to search for published literature, conference proceedings, government documents, theses, working papers, and reports, and (2) Specific global and national websites that might include HS information were also visited.

Estimation of HS degree (measure of heat load)

The degree of HS experienced by animals is estimated by the temperature-humidity index (THI) that includes both ambient temperature and relative humidity (Marai et al., 2001). Measuring the heat load imposed on an animal using air temperature (dry bulb temperature) can be misleading. A more useful measure is the wet bulb temperature, which takes relative humidity into account (Sparke et al., 2001). When the temperature is expressed in °C, the equation to determine THI for sheep and goats according to Marai et al. (2001) is as follows: THI = dry bulb temperature °C − {(0.31 − 0.31 relative humidity) (dry bulb temperature °C − 14.4)}. The values obtained indicate the following: <22.2 = absence of HS; 22.2 to <23.3 = moderate HS; 23.3 to <25.6 = severe HS and ≥ 25.6 = extreme severe HS (Marai et al., 2001). When temperature is measured in °F, the equation is as follows: THI = dry bulb temperature °F − {(0.55 − 0.55 relative humidity) (dry bulb temperature °F − 58)}. The obtained values indicate the following: values <82 = absence of HS; 82 to <84 = moderate HS; 84 to <86 = severe HS and ≥ 86 = extreme severe HS (LPHSI, 1990). Comparisons based on THI between dairy goats and dairy cows revealed that goats are more adapted than cows to the effect of HS (i.e., extreme HS: THI $\geq$ 84 for cows and $\geq$ 90 for goats) (Silanikove and Koluman, 2015). It is worth to mention here that THI does not take into account the effect of radiation (Silanikove, 2000 b), and since most goat and sheep farming occur under grazing situations, THI poorly reflected HS. In fact, HS is much higher under grazing situations than as reflected by the THI.

Thermoregulation and heat dissipation mechanisms by sheep and goats

Sheep and goats are homeothermic animals, and can maintain near constant body temperature under a wide range of environmental conditions (Lefcourt and Adams, 1998). Thermoregulation is the mean by which an animal maintains its body temperature and it involves a balance between heat gain and loss (Crawshaw, 1980). The range of temperature when the animal needs no additional energy to maintain its body temperature is called thermoneutral zone. Animals function most efficiently within their thermoneutral zone, while above the upper and below the lower critical temperatures, the animals are stressed and the environment constrains the production process (Da Silva, 2002). The thermoneutral zone is about 12–32ºC for sheep (Taylor, 1992), and 12–24°C for goats in the hot regions of the world (Nikitchenko et al., 1988; Mishra, 2009). HS occurs in animals when there is an imbalance between heat production within the body and its dissipation. In response to stress, animals set physical, biochemical and physiological processes into play to counteract the adverse effect of HS and maintain thermal equilibrium (Castanheira et al., 2010). Most of the adjustments made by an animal involve dissipating heat to the environment and reducing the production of metabolic heat (Silanikove, 2000 a, b). The hyperthermia during exposure to HS is the result of the decreased thermal gradient between the animal and the surrounding environment, and as a result sensible heat loss (convection, conduction and radiation) becomes less effective (Al-Haidary, 2004). Under these conditions an animal must rely on evaporative cooling mechanisms from its skin and respiratory tract (Al-Haidary, 2004). Exposure of animals to HS leads to drastic changes, including a decrease in feed intake efficiency and utilization, disturbances in water, protein, energy and mineral balances, enzymatic reactions, hormonal secretions and blood metabolites (Marai et al., 2007), reduction in fecal and urinary water losses and an increase in sweating, respiration and heart rates (Silanikove, 2000 a).

Animals maintain their body temperature within tight limits over a wide range of ambient temperatures by balancing heat loss or gain and heat production (Crawshaw, 1980). Elevation of body temperature is the most obvious measure indicating that an animal is exposed to an unacceptable heat load (Mader et al., 2006). The exposure of sheep and goats to elevated ambient temperatures induces an increase in the dissipation of excess body heat in order to negate the excessive heat load. Dissipation of excess body heat is excluded by evaporation of water from the respiratory tract and skin surface via panting and sweating, respectively. When the physiological mechanisms of the animal fail to negate the excessive heat load, the rectal temperature increases (Marai et al., 2007). Evaporation becomes the most important avenue for heat dissipation, since sweating in sheep is much less important than respiratory evaporation due to the presence of a wool coat (Marai et al., 2007).

When the environmental temperature rises to 36°C, the ears and legs of sheep and goats dissipate a high proportion of the heat, as these areas form about 23% of each animal's body surface area (Johnson, 1987). In sheep, the respiratory response to increased ambient temperatures involves both an increased panting rate, followed by slower and deeper panting (Hales and Webster, 1967). As ambient temperature approaches skin temperature, the rate of heat dissipation through sensible heat loss decreases (Caulfield et al., 2014). As HS progresses, there is recruitment of evaporative processes, primarily sweating and increased respiration rate (Mortola and Frappell, 2000). When HS becomes more severe, the depth of respiration increases back to near normal tidal volume while the respiration rate remains elevated above normal (Sparke et al., 2001). Evaporation of water requires a vapor pressure gradient for loss of heat energy as water evaporates to the surrounding air, but in very humid conditions this gradient is reduced, and therefore evaporative heat loss from the skin is reduced (Barnes et al., 2004). When the air temperature rises to near body temperature, this means that heat loss from panting also becomes limited (Sparke et al., 2001). There are basic differences in thermoregulation between goats and sheep. Goats are more thermo-labile than sheep, having different process of adaptation mechanisms (i.e., anatomical, morphological, physiological, feeding behavior, metabolism, and performance). Silanikove (2000 b) and Silanikove and Koluman (2015) provided an integrative explanation of the ability of goats to survive and produce better than other ruminants in harsh environments: (1) skillful grazing behavior (they eat diets composed of browse [tree-leaves and shrubs]); (2) small body size; (3) high digestive efficiency; (4) low metabolic requirements; (5) ability to reduce metabolism; (6) efficiency of utilization of high fiber forage; (7) higher surface area of absorptive mucosa than in grass and roughage eaters; (8) capacity to increase substantially the volume of the foregut when fed high-fibrous food; (9) effective urea recycling to the rumen allowing goats to effectively digest low-protein feeds; (10) efficient use of water; and (11) large salivary glands.

The characteristics of the outer surface of an animal's body are of great importance in the relationship between the animal and its ambient temperature. The first defense layer protecting animals from direct sunlight is provided by the coat, and this protection differs according to coat color, depth and length (Silanikove, 2000 a; Da Silva, 2002; Jakper and Kojo, 2014). Animals with a dark coat – and therefore with greater absorption of thermal radiation – are more susceptible to heat than those with a light colored coat at the same temperature (Silanikove, 2000 a). White or light brown goats do better than dark brown or black goats (Acharya et al., 1995). In addition, light brown coat color sheep are more tolerant to heat under hot environmental conditions (Okoruwa, 2015). Helal et al. (2010) mentioned that the thermal insulation increases by increasing the coat depth and attributed to the air space between the hair fibers. Carpet-type wool, as compared with denser wool types, seems to confer protection from solar radiation while at the same time allowing effective cutaneous evaporative cooling (Cain et al., 2006). The long hair serves as an insulator from the heat, providing a hair buffer zone between the outer environment and the animal's body (Jakper and Kojo, 2014). Helal et al. (2010) showed that long haired goats (130 mm) tolerated heat better than short haired goats (97.5 mm). Also, studies have shown that sheep with a wool length of 8 mm were more stressed than those with a wool length of 20 mm (MacFarlane, 1958). While optimum fleece length for protection from radiation is 40 mm (Thwaites, 1985), a thick fleece interferes with evaporative water loss from the skin. In indigenous sheep breeds from arid and semi-arid regions, the external localization of the fat in the tail allows better heat dissipation from the rest of the body (Degen and Shkolnik, 1978), since the body becomes less insulated by the fat tissue.

Heat stress effects on behavioral responses of sheep and goats

Despite the numerous published studies on the impact of HS on productive and reproductive parameters, little is published about the behavioral changes in sheep and goats during HS. However, animals behave in various ways during HS, and that can provide insights on how and when to cool them. The range of behavioral responses affects heat exchange between the animal and its environment by reducing heat gain from radiation and increasing heat loss via convection and conduction (Hafez, 1968). Behavioral responses of sheep and goats under HS include: bunching in the shade (Silanikove, 2000 a), slobbering, panting, open-mouth breathing, decreasing feed intake and increasing water consumption (Caroprese, 2008; Facanha et al., 2012 b). In severe cases of HS in sheep and goats, lack of coordination, trembling and down animals may be seen. In addition, desert animals usually use nocturnal activity (most active during the night) to reduce heat load in hot conditions (Cain et al., 2006).

Seeking shade is a conspicuous form of behavioral adaptation (Silanikove, 1987). If shade is not available, animals will change their posture to the vertical position in respect to the sun in order to reduce the effective area for heat exchange (Cain et al., 2006). Animals can change posture, i.e. stand or spread out to increase surface area for heat loss and reduce activity (Bligh, 1985). For the same purpose, sheep tend to crowd and to stand intimately side by side to reduce the effect of HS on them (Silanikove, 2000 a). Under severe HS, animals moisten their body surface with water, saliva or nose secretions (Silanikove, 2000 a). Panting is thought to be a more important heat loss mechanism in sheep and goats (Thwaites, 1985). Studies showed that dry matter intake decreases significantly following exposure to HS in sheep (Monty et al., 1991) and goats (Nardone et al., 1991). Under HS, rumination time decreased by 76%, and this reduction seems to be as a result of the increase in the number of times the sheep chews, which is related to the eating efficiency (Hirayama et al., 2000). Animals may react either by physiological or behavioral responses, but most often a combination of both (Stull, 1997). For example, goats expressed decreased urination and defecation under HS conditions (Alam et al., 2011; Shilja et al., 2015). The reason for reduced urination frequency could be due to increased respiratory and cutaneous cooling mechanisms which might lead to severe dehydration, thereby leading to a reduction in their urination frequency (Shilja et al., 2015). Also, the reduction in defecating frequency could be an adaptive mechanism of these animals to conserve body water (Shilja et al., 2015).

In extreme heat, grazing ruminants decrease their grazing time, tend to lie down to reduce their locomotion and spend more time in the shade (Silanikove, 1987; Silanikove, 2000 a, b). Standing and lying are behavioral adaptive mechanisms to prevent additional heat load from the ground and to facilitate effective heat dissemination (Shilja et al., 2015). In da Costa et al. (1992) they showed that sheep spend more time lying down than standing up during summer at air temperatures of 24–45°C. In contrast, Alam et al. (2011) concluded that heat-treated goats (4–8 h heat exposure for 18 days) showed an elevation in standing time (445 vs. 390 min), and spent less time lying down (50 vs. 90 min) as compared to control goats.

Heat stress effects on the physiological responses of sheep and goats

High ambient temperature has potentially several physiological adverse effects that result in a tremendous economic loss for the sheep and goat industry. These include aberration of reproductive functions, oxidative stress, enzymatic dysfunction (Hall et al., 2001), electrolyte imbalances (West et al., 1991), promoting an unfavorable endocrine balance and reducing feed intake (Adedeji, 2012), and meat quality (Kadim et al., 2008). Physiological adjustments are essential to maintain normal body temperature and prevent hyperthermia (Lowe et al., 2001). Physiological parameters like respiration rate, heart rate and rectal temperature give an immediate response to HS (Helal et al., 2010; Sanusi et al., 2010), and consequently the level of animal discomfort/comfort. Changes in respiration rate, heart rate and rectal temperature have been frequently used as indices of physiological adaptability to HS in small ruminants (Marai et al., 2007; Adedeji, 2012; Gupta et al., 2013; Sharma et al., 2013). Increased body temperature and respiration rate are the most important signs for HS in sheep and goats (Al-Haidary, 2004; Alam et al., 2011). However, it is important to mention that complexity and a suite of physiological changes due to HS response can differ from species to species, individual to individual, and the hormonal status of the animal.

Rectal temperature

The body temperature is a good measure of heat tolerance in animals. Maintenance of body temperature is under neuronal control in a negative feedback system (Fecteau and White, 2014). Temperature sensitive neurons (warm and cold), which are found in the preoptic region of the anterior hypothalamus, are considered a thermostat with a desired set point (Robinson, 2002). Temperature sensors are also found in the skin and deep tissues of the body (e.g., thorax, around the great veins of the abdomen and in the abdominal viscera) (Robinson, 2002). Fever and hyperthermia are two distinct causes of high body temperature. Fever is a complex reaction to pyrogens that not only cause the body's thermoregulatory set point to rise, but also stimulates an acute-phase reaction and activates numerous metabolic, endocrinologic and immunologic systems and behaviors (Wrotek et al., 2011; Fecteau and White, 2014). While hyperthermia represents a failure in thermoregulation (uncontrolled heat production, poor heat dissipation or an external heat load), this does not involve a thermoregulatory set point (Wrotek et al., 2011; Fecteau and White, 2014), and the microbial products and pyrogenic cytokines are not directly involved (Wrotek et al., 2011). It is likely that most cases of elevated body temperature after stroke are due to fever, and not to hyperthermia (Wrotek et al., 2011).

The temperature in the rectum is representative of deep body temperature (Bligh, 1957). It represents the result of all heat gain and heat loss processes of the body (Gupta et al., 2013). Rectal temperature is considered a good index of body temperature even though there is a considerable variation in different parts of the body core at different times of the day (Srikandakumar et al., 2003). Rectal temperature is an indicator of thermal balance and may be used to assess the adversity of HS which can affect growth, lactation and reproduction (West, 1999). A rise in rectal temperature of 1°C or less is enough to reduce performance in most livestock species (Shebaita and El-Banna, 1982), which makes body temperature a sensitive indicator of the physiological response to HS because it is nearly constant under normal conditions (Silanikove, 2000 a). The physiological adjustments that animal makes to prevent body temperature from raising during HS help prevent death from heat stroke, but also reduce productivity (Silanikove, 1992). For example, the increase in body temperature is associated with a marked reduction in feed intake, redistribution in blood flow and changes in endocrine functions that will negatively affect productive and reproductive performance (Eltawil and Narendran, 1990).

Domestic animals are homeotherms which tend to maintain a constant body temperature through a balance of heat gain and loss. The allowable variation in the body temperature is small (Oladimeji et al., 1996). Its variation above and below normal is a measure of the animal's ability to resist stress environmental factors. However, Fasoro (1999) reported rectal temperature between 39.2°C and 39.8°C for goats; while Heath and Olusanya (1985) and Okoruwa (2015) reported a range of 38.3–39.9°C for sheep. If rectal temperature exceeds 41.7ºC, death may occur as the animal cells begin to degenerate (Thwaites, 1985; Marai et al., 2007). Heat exposure increased goats' rectal temperature from 37°C to 41°C (Al-Tamimi, 2007; Okoruwa, 2014). Also, sheep exposed to heat showed higher rectal temperature of 39.5–39.8°C (Marai et al., 2000; Srikandakumar et al., 2003). In contrast, no rectal temperature changes were reported in goats (Alam et al., 2011; Facanha et al., 2012 a) and in sheep (Wojtas et al., 2014) exposed to heat treatments.

Heart rate

The heart rate is the regular beat rate of the arteries as the blood is pumped through them to the heart (Heath and Olusanya, 1985). Heart rate (expressed through beats/min) can be rapidly altered due to animal biological activities or by external factors such as temperature. Normal heart rates range from 90 to 95 beats/min (Heath and Olusanya, 1985) for goats, and from 70 to 80 beats/min for sheep (Zaytsev et al., 1971). Heat exposure showed a higher heart rate in goats (74 to 91 beats/min: Alam et al., 2011; Okoruwa, 2014) and sheep (83 beats/min: Al-Haidary et al., 2012; 90 to 107 beats/min: Wojtas et al., 2014). Exposure to HS reduced the daily average of heart rate in sheep (from 115.7 to 85.8 beats/min: Al-Haidary, 2004). In contrast, Sunagawa et al. (2002) did not detect any significant changes in heart rate when sheep were exposed to HS. The heart rate increases under HS conditions, and this increases blood flow from the core to the surface of the body to give a chance for more heat to be lost by sensible (conduction, convention and radiation) and insensible (diffusion water from the skin) means (Alexiev et al., 2004; Marai et al., 2007; Adedeji, 2012). However, heart rate reflects primarily the homeostasis of circulation along with the general metabolic status. The findings that heart rate responds to heat exposure may be explained by the fact that heart rate is positively correlated with metabolic rate (Barkai et al., 2002). On the other hand, exposure to HS is known to reduce the metabolic heat production to minimize the heat load and maintain normal body temperature (Al-Haidary, 2004). Therefore, HS reduces the heart rate, and the marked acceleration of the heart rate occurred during the hottest part of the day (Alexiev et al., 2004). Aharoni et al. (2003) have suggested that heart rate decreased because of the general effort of the animal to decrease heat production.

Respiratory rate

The respiration rate (breaths/min) can change frequently and it is indirectly influenced by the animal's activities (metabolism and muscle activity) (Devendra, 1987), and environmental conditions (Silanikove, 2000 b). Respiration rate is a practical and reliable measure of heat load and an indicator of HS (Alam et al., 2011; Okoruwa et al., 2013). The respiration rate is recorded by counting flank movements per minute from a distance of 4–5 m without disturbing the animals (Shilja et al., 2015) or from a non-obstructive distance (Adedeji, 2012). The basal reference respiration rate is 16–30 breaths/min in sheep (Zaytsev et al., 1971), and 15–30 breaths/min in goats (Robertshaw and Dmi'el, 1983). Thus, measuring respiration rate and deciding if an animal is panting, and qualifying the severity of HS according to panting rate (breaths/min) (low: 40–60, medium: 60–80, high: 80–120, and severe HS: >200) appears to be the most accessible and easiest method for evaluating the impact of HS on animals under extreme conditions (Silanikove, 2000 a, b). In this regard, Silanikove (2000 b) reported that the respiration rate approaching 300 breaths/min with open-mouthed panting is indicative of severe HS. Increased respiration rate following HS has been reported in sheep (74 breaths/min: Gadberry et al., 2003; Al-Haidary et al., 2012) and goats (22–162 breaths/min: Facanha et al., 2012 a; 23 breaths/min: Okoruwa, 2014). The increased respiration rate is probably indicating an effort of animals to maintain their normal body temperature by increasing their heat dissipation through increasing respiratory evaporation (Hamzaoui et al., 2013).

Heat stress effects on molecular/cellular responses of sheep and goats

In mammalian cells, nonlethal heat shock produces changes in gene expression and in the activity of expressed proteins, and results in cell stress response (Lindquist, 1986). The cellular response is one component of the acute systemic response to HS. High temperature results in alterations and damages at the cellular level. Cell components (i.e. unfolding and subsequent aggregation of proteins) are negatively affected by HS (Caspani et al., 2004; Roti, 2008). Protein synthesis is particularly affected by HS but recovers quickly (Rhoads et al., 2013), whereas resumption of DNA synthesis requires a period of time (Henle et al., 1979). The cellular response includes: activation of heat shock factors, increased expression of heat shock proteins, increased glucose and amino acid oxidation, reduced fatty acid metabolism, activation of endocrine and immune systems via extracellular secretion of heat shock proteins (Collier et al., 2008). Heat shock factors exist in multiple isoforms in mammals, i.e. heat shock factors 1, 2 and 4. Heat shock factor 1 is the central transcription factor involved in the heat shock response (Baler et al., 1993). Heat shock factor 1 is activated in response to HS and oxidative stress (Westerheide and Morimoto, 2005). Heat shock factor 2 is primarily transcribed in response to the inhibition of proteasome activity and thus complements the response of heat shock factor 1 to an increase in misfolded proteins (Mathew et al., 1998). Heat shock proteins contribute to cell survival by reducing the accumulation of damaged or abnormal polypeptides within cells (Parsell and Lindquist, 1993). They play a crucial role in intracellular transport, maintenance of proteins in an inactive form, and the prevention of protein degradation (Neuer et al., 2000). Heat shock proteins 27, 60, 70, 90 and 110 are major heat shock proteins in mammalian cells (Park et al., 2000), each with different functions and cellular locations (Feige and Polla, 1994). Heat shock proteins are the best studied genes whose expressions are affected by HS. Expression of many heat shock proteins (i.e. 32, 40, 60, 70, 90 and 110) is increased during HS (Sharma et al., 2013). Heat shock protein 70 is used as a biomarker of cellular stress (Rhoads et al., 2013), and plays a heightened role in cryoprotection (Volloch and Rits, 1999), and its expression level is indicative of magnitude and duration of HS (Mizzen and Welch, 1988). In the nucleus, heat shock factor trimmer complexes bind promoters containing heat shock elements to activate HS target gene transcription (Collier et al., 2008; Gupta et al., 2013).

Heat stress effects on hematological and biochemical responses of sheep and goats

The blood profile of animals is sensitive to changes in the environmental temperature and is an important indicator of physiological responses to the stressing agent (Okoruwa, 2014). Determination of blood parameters may be important in establishing the effect of HS. HS has an effect on animals as revealed by changes in hematological parameters, i.e. red blood cells, white blood cells, hemoglobin, lymphocytes, neutrophil, eosinophil, monocyte, granulocytes, packed cell volume and blood pH. When exposed to HS, goats showed an increased amount of red blood cells, packed cell volume, hemoglobin, white blood cells, neutrophil, eosinophil, lymphocyte and monocyte (Alam et al., 2011). Also, packed cell volume, hemoglobin and red blood cells were higher under HS in goats (Okoruwa, 2014) and sheep (Sanusi et al., 2010). In contrast, HS decreases packed cell volume and hemoglobin in sheep and goats (Srikandakumar et al., 2003; Sivakumar et al., 2010), and white blood cells in goats (Okoruwa, 2014). However, higher packed cell volume values are an adaptive mechanism of animals to provide the necessary amount of water, where more water is transported into the circulatory system, required for the evaporative cooling processes (Al-Haidary, 2004). Another explanation of the increase in packed cell volume and hemoglobin levels could be either increased un-attack of free radicals on the red blood cells membrane, which is rich in lipid content, and ultimate lysis of red blood cell (Leonart et al., 1989) or availability of adequate nutrients for synthesis of hemoglobin as the animal consumes more feed or decreases voluntary intake under HS (Srikandakumar et al., 2003; Gupta et al., 2013).

The acid-base balance is a complex physiological process to maintain a stable pH in an animal's body. The body utilizes different mechanisms to combat any change in acid-base balance, i.e. chemical buffering, respiratory adjustment of blood carbonic acid (H_2CO_3) and excretion of hydrogen ions or bicarbonate (HCO_3-) by the kidneys (Houpt, 1989). Metabolic acidosis and alkalosis involving HCO_3- as well as respiratory acidosis and alkalosis related to partial pressure of CO_2 may occur under HS.

The vital limits of pH variation for mammals are between 7.35 and 7.45 (Houpt, 1989; Constable, 1999) and regulated by a complex system of buffers (H_2CO_3 and HCO_3-). Blood pH increased under HS in sheep and goats (Sivakumar et al., 2010; Srikandakumar et al., 2003). The increase in pH may be due to reduced H_2CO_3 (Benjamin, 1981), total CO_2, HCO_3- (Hamzaoui et al., 2013) and base excess in blood and extra-cellular fluid (Sivakumar et al., 2010). The secretion of HCO_3- in urine and its reabsorption suggest a large requirement and turnover of body HCO_3- to maintain blood pH during HS (Hamzaoui et al., 2013).

Blood biochemical parameters reflect the health (detecting possible diseases) and the metabolic status of an animal (evaluating the body's internal condition, the function of organs [e.g. kidneys and liver], and metabolic processes in the body), which are widely used in clinical situations. HS affects biochemical parameters, i.e. alkaline phosphatase, alanine aminotransferase, aspartate transaminase, lactate dehydrogenase, total protein, albumin, globulin, glucose, cholesterol, blood urea nitrogen, non-ester fatty acids, beta-hydroxybutyrate, creatinine, triiodothyroxine, thyroxine, cortisol, prolactin, sodium, potassium, chloride, calcium, magnesium, iron, manganese, copper, zinc and oxidative stress parameters (glutathione peroxidase, glutathione reductase, superoxide dismutase and lipid peroxides).

Enzymes

Metabolic regulators are important in elucidating a picture of modulation in physiological mechanisms during stressed conditions and are best assessed by determining the enzymes governing various metabolic reactions in plasma/serum (Gupta et al., 2013). Enzyme levels reflect the metabolic activities during stress. HS reduces alkaline phosphatase and lactate dehydrogenase activity in sheep (Sevi et al., 2001) and goats (Helal et al., 2010). The decrease in these enzymes during HS is due to the decrease in thyroid activity during HS (Helal et al., 2010). Serum level of aspartate transaminase and alanine aminotransferase is helpful in the diagnosis of the welfare of animals. The serum alanine aminotransferase value increases during HS in goats (Sharma and Kataria, 2011).

Proteins

Significant decrease in total protein concentration in goats has been reported during HS (Dangi et al., 2012). Total plasma protein, albumin and globulin levels decrease in goats subjected to HS (Helal et al., 2010). This may be due to an increase in plasma volume as a result of HS, which results in a decrease in plasma protein concentration. In contrast, HS increased total protein and albumin in goats (Okoruwa, 2014) and could be due to dehydration which has been reported to occur as a result of increased respiration rate.

Glucose, cholesterol, blood urea nitrogen, non-ester fatty acids and beta-hydroxybutyrate

Studies on glucose, cholesterol, blood urea nitrogen, non-ester fatty acids and beta-hydroxybutyrate in response to HS are conflicting. Glucose and cholesterol levels show greater differences under HS conditions than in the comfort zone. HS conditions decrease glucose and cholesterol levels in goats (Ocak et al., 2009). The decrease in glucose level could be related to the decrease in availability of nutrients and lower rate of propionate production (Mohamad, 2012), or due to the increase in plasma glucose utilization to provide energy for muscular expenditure required for high muscular activity associated with increased respiration rate (Sejian and Srivastava, 2010). The decrease in cholesterol level may have a relation with the increase in total body water or the decrease in acetate concentration, which is the primary precursor for the synthesis of cholesterol (Gupta et al., 2013). In sheep, glucose levels increase during HS (Al-Haidary et al., 2012). Conversely, HS had no effect on glucose and blood urea nitrogen in goats (Hamzaoui et al., 2013). Non-ester fatty acids and beta-hydroxybutyrate are most indicative of the animal's energy status. Hamzaoui et al. (2013) reported that a reduction in feed intake and body weight under HS was not accompanied by body fat mobilization as non-ester fatty acid concentration did not vary between HS and control goats. Non-ester fatty acid concentration is typically reduced in heat-stressed sheep (Al-Mamun et al., 2007) despite marked reduction in feed intake. Exposure to HS resulted in higher non-ester fatty acids in sheep (Sevi et al., 2001) and beta-hydroxybutyrate concentration in goats (Salama et al., 2014).

Hormones

Hormones (i.e. thyroxine, triiodothyroxine, prolactin, leptin, adiponectin, growth hormone, glucocorticoids, mineralocorticoids, catecholamines and antidiuretic) are involved in thermal adaptation and could be important indicators for assessment of stress in animals (Minton, 1994; Sivakumar et al., 2010). Higher body temperature during exposure to HS is associated with a significant depression in thyroid gland activity resulting in lower levels of thyroid hormone (Ross et al., 1985). Decreased thyroid hormone level during HS is an adaptive response and affects the hypothalamic-pituitary-adrenal to decrease thyrotropin releasing hormone (Johnson, 1985), which enables animals to reduce metabolic rate and heat production (West, 1999), and reduces the amount of heat produced by the cells (Barnes et al., 2004). In goats, Helal et al. (2010) and Sivakumar et al. (2010) reported a decrease in plasma concentration of triiodothyroxine and thyroxine levels. Exposure to HS did not result in significant changes in the thyroid hormone concentrations in sheep (Al-Haidary, 2004). Cortisol plays an important role in all types of stress. An increased cortisol level during HS was reported in sheep (Barnes et al., 2004) and goats (Sivakumar et al., 2010). The prolactin level increased in goats under HS (Sivakumar et al., 2010). In addition, leptin and adiponectin concentrations in goats were affected by HS (Al-Dawood, unpublished data).

Electrolytes

HS challenges the animal's ability to maintain its mineral balance (Sivakumar et al., 2010). The serum concentrations of sodium, potassium and chloride decreased in goats subjected to HS due to the fact that HS animals lost more potassium and chloride in sweat than non-HS animals, and the blood volume expanded where water is transported in the circulatory system for evaporative cooling (Al-Haidary, 2004).

Oxidative stress parameters

HS stimulates excessive production of free radicals such as reactive oxygen species (superoxide anion radicals, hydroxyl radical, hydrogen peroxide and singlet oxygen) which are continuously produced in the course of normal aerobic metabolism, and they can damage healthy cells if not eliminated (Rhoads et al., 2013). Normal cells have the capacity to detoxify superoxide radicals using antioxidant enzymes (superoxide dismutase, glutathione peroxidase, glutathione reductase and catalase) and non-enzymatic antioxidants including vitamins (C, A and E), and proteins (albumin, transferrin, glutathione) (Kumar et al., 2011 b). Kumar et al. (2011 a) reported that oxidative stress increases in goats during summer as superoxide dismutase increases.

Heat stress effects on the immunological responses of sheep and goats

HS impairs immune function and increases disease susceptibility (Kelley, 1985). The immune system is classified into two categories: innate and adaptive immunity. Components of the innate defense include the physical barrier of the skin and mucous epithelia, leukocytes (macrophages, neutrophils and natural killer cells), non-immune cells (epithelial and endothelial cells), and certain soluble mediators (cytokines, eicosanoids and acute phase proteins). Inflammation is one of the hallmarks and first responses of the innate immune system to infection, and is associated with heat, redness, pain, swelling and impaired function. It has two main functions: remove the injurious agents and initiate the tissue healing process (Lippolis, 2008; Sordillo et al., 2009). The local inflammation that develops at the site of infection induces the acute phase response. The acute phase response is a complex systemic innate-defense system activated by trauma, infection, inflammation and stress to prevent tissue damage, eliminate any infective organisms and activate the repairing processes to restore homeostasis. It is induced by the release of inflammatory cytokines, especially Interleukin-1, Interleukin-6 and tumor necrosis factor-α from the macrophages or blood monocytes at the site of inflammatory lesions or infections. The liver is the main site of synthesis of most acute phase proteins. Cytokines therefore act as mediators between the local site of injury and the hepatocytes (liver) to produce and release the acute phase proteins (the above section reviewed by Jain et al., 2011).

The acute phase proteins are defined as proteins whose plasma concentrations increase or decrease classifying them into positive (i.e. C-reactive protein, serum amyloid A, haptoglobin), and negative (i.e. albumin, transferrin) acute phase proteins, respectively. The maximum concentration is usually reached within 24–48 hours after stimulation and declines with recovery from the infection (Jain et al., 2011). In ruminants, there are two major acute phase proteins: haptoglobin and serum amyloid A which both increase during tissue injury and disease (Grönlund et al., 2005; Gonzalez et al., 2008). Acute phase proteins are recognized as promising tools to assess welfare, health and performance in animal production (Petersen et al., 2004). The data on the use of acute phase proteins as biomarkers and potential indicators of stress in sheep and goats are rare. Haptoglobin and serum amyloid A concentrations increased in goats exposed to HS, thus it might be that they are useful and sensitive markers in monitoring HS in goats (Al-Dawood, unpublished data). Goats exposed to HS increased circulating haptoglobin when they were metabolically challenged (Hamzaoui et al., 2013).

Heat stress effects on milk quantity and quality of sheep and goats

The reduction in quantity and quality of milk is a major economic impact of HS in dairy animals. HS decreases milk production of dairy animals, and half of this reduction in milk yield is due to reduced dry matter intake (Hamzaoui et al., 2013). Two main mechanisms may be involved in the response of lactating animals to stress: the local mechanism (Silanikove, 2000 a) which connects the plasmin-plasminogen system to the autocrine inhibition of lactation, and the systemic mechanism which takes into account the role of hypothalamic-pituitary-adrenal in determining the rate of milk secretion (Matteri et al., 2000). Silanikove (2000 a) showed that stress activates the hypothalamic-pituitary-adrenal axis that liberates cortisol into blood plasma. This induces the liberation of the plasmin activator from the mammary epithelial cells into the mammary cistern, where it activates the plasmin system that degrades β-casein and produces the residue 1–28 β-casein, which is also called proteoso-peptone channel blocking. Proteoso-peptone channel blocking inhibits the ion channels in mammary epithelia apical membranes and thus also inhibits lactose and monovalent ion secretion, which results in a decrease in milk volume (Sevi et al., 2001; Dwyer and Bornett, 2004). A secondary effect of stress is the inhibition of prolactin synthesis by the pituitary gland due to the hypothalamic release of dopamine. Both situations cause a transient metabolic energy surplus due to reduction in energy output by the milk and increase in mobilization of stored energy. This is caused by a sharp increase in glucocorticoids, followed by an increase in insulin and adipose tissue uptake capacity (Kandemir et al., 2013).

Milk yield in dairy goats decreased as THI index value increased, and for each 1 unit increment of THI there is a decrease of 1% in milk yield (Salama et al., 2014). Silanikove and Koluman (2015) summarized the HS risk on milk yield in dairy goats according to THI as following: Normal (no effect on milk yield) THI < 80; Alert (modest effect on milk yield) $80 \leq$ THI < 85; Danger (severe effect on milk yield) $85 \leq$ THI < 90; and Extreme (can result in death) THI ≥ 90. Lactating goats exposed to moderate or severe (THI = 81 or 89) HS for four days lost milk yield of 3% or 13%, respectively (Sano et al., 1985). Brown et al. (1988) also reported that exposure of dairy goats to moderate HS (34°C; THI = 79) for five weeks depresses milk yield. Furthermore, dairy goats kept under HS in a climatic chamber reduce their milk yield by 3–10% (Salama et al., 2012, 2014). On the contrary, Hamzaoui et al. (2013) found that dairy goats were able to maintain milk yield under HS conditions (31–37°C; THI = 77 and 65, respectively). The content of protein and protein fractions in milk were reduced under HS (Hamzaoui et al., 2013). Decreased protein intake and increased sweat secretion that contains protein and urea might have limited the availability of amino acids for milk protein synthesis (Salama et al., 2014). Moreover, the reduction in milk protein content under HS may be due to lowered microbial protein synthesis in the rumen because of changes in rumen environment by the high water intake (Hamzaoui et al., 2013). It is suggested that decreased mammary synthesis of milk protein is the reason for low milk protein during the HS (Bernabucci et al., 2002). Also, it has been observed that dairy goats under HS conditions produce milk with less fat concentration (Salama et al., 2012, 2014). In contrast, milk fat contents did not differ between HS and control goats (Hamzaoui et al., 2013). Thus, milk of HS goats had different coagulation properties which could have an important impact on cheese industry (Salama et al., 2014).

Heat stress effects on meat quality and carcass characteristics of sheep and goats

Heat stress affects meat quality, carcass characteristics and the organoleptic quality of sheep and goats. The degradation of meat quality variables (pH, color, texture and moisture) is referred to as dark cutting or dark-firm dry, high pH, low glycogen meat (Schaefer et al., 1997). Rana et al. (2014) explained how the meat quality may be hampered by various physiological phenomena. Firstly, HS provokes sufficient adrenaline response which stimulates peripheral vasodilatation and muscle glycogenolysis, and if exposure is protracted before slaughter it could lead to high pH and darker meat. Secondly, if an animal exercises and develops hyperthermia before it is slaughtered, the combination of high temperature and anaerobic metabolism leads to an early and stronger rigor. Thirdly, high temperatures lead to dehydration in water deprived animals and this can affect meat quality by making it darker in color through shrinkage of the myofibrills, and because of its dryness it has less weight loss during cooking.

Sheep and goats slaughtered under an ambient temperature of ~35°C had a higher pH (5.78 vs. 5.65) level and myofibrillar fragmentation index in muscles (indicator of the extent of myofibrillar protein degradation of meat post-slaughter: 86.88% vs. 85.59%), lower color (lightness, redness and yellowness), and expressed less juice (35.74 g/cm^2 vs. 36.84 g/cm^2) than those slaughtered at 21°C, which indicates that the seasonal temperatures were the main reason for differences in meat quality (Kadim et al., 2008). In goats, HS (27°C; 88%) significantly affects the pre-slaughter and carcass parameters (increased cooking loss [43% vs. 36%] and pH [6.30 vs. 6.16]), as well as by-product (increased weight of blood [173 vs. 437 g], pluck [370 vs. 573 g], heart [32 vs. 50 g], spleen [20 vs. 43 g] and kidney [20 vs. 43 g] rather than non-heat stressed group (Hashem et al., 2013). Also, carcass characteristics and meat quality of sheep are affected by HS (28°C; 82%), as drip loss increased more in the non-exposure group (18.54%) than the treated groups (14.62%), and significant differences were found in the weight of heart (45 vs. 16 g), kidney (17 vs. 12 g), lung + trachea (110 vs. 70 g) between control and heat treated groups (Rana et al., 2014).

Heat stress effects on feed intake of sheep and goats

Interaction between stress and nutrition results in nutrient deficiency as HS is associated with marked reduction in feed intake (West, 1999). However, decreased feed intake could be due to reduction in the rate of passage of digesta, which increases gut fill for longer and depresses intake (Rana et al., 2014). Also, change in the thermal environment induces a decrease of blood flow to the rumen (76% under severe stress and 32% under moderate stress), and reduction in both ruminal motility and rumination (da Costa et al., 1992). There is also a direct effect of HS on the feeding center of the hypothalamus, resulting in a hormonal response, which could also decrease metabolic rate (Johnson, 1985; West, 1999). For example, as the thyroid secretion rate is reduced during HS and thyroid hormones affect the rate of food passage, the decrease in the passage rate may possibly have also been a result of a decline in the thyroid secretion rate (Silanikove, 1987). Heat-stressed animals decrease feed intake in an attempt to create less metabolic heat because the heat increment of feeding is an important source of heat production (Kadzere et al., 2002). Also, the maintenance requirements increased by 30% because of HS (NRC, 2007) and the energy intake would not be enough to cover the daily requirements which results in an apparent body weight loss (Hamzaoui et al., 2013). In fact, heat-stressed animals enter a bioenergetic state similar (but not to the same extent) to the negative energy balance observed in early lactation (Moore et al., 2005). Negative energy balance is associated with a variety of metabolic and hormonal changes; it is likely that many of the negative effects of HS on production, animal health and reproduction indices are mediated by the reduction in energy balance (Moore et al., 2005).

Literature reported a marked loss of feed intake and body weight of animals exposed to HS. Exposure of animals to HS augments the efforts to dissipate body heat, resulting in a decline in feed intake (Kandemir et al., 2013). Feed intake reduction due to HS has been reported in sheep (Kandemir et al., 2013) and goats (Hamzaoui et al., 2013; Salama et al., 2014). In addition, body weight, daily feed intake and gain decreased under HS conditions in sheep (Kandemir et al., 2013) and goats (Okoruwa, 2014). Loss of body weight during HS might be attributed to the increase in energy expended for heat dissipation through respiratory evaporation, and subsequently to the reduction in the amount of water available for storage (Ocak et al., 2009; Okoruwa, 2014). Studies showed that dry matter intake decreased following exposure to HS in sheep (Nardone et al., 1991). Dairy goats decreased their dry matter intake by 30% (Salama et al., 2012) under HS conditions. Numerous nutritional changes through researcher guidance to producers/farmers in diet, are needed during HS to maintain feed intake, increase nutrient density and minimize the negative effect of HS (West, 1999).

Heat stress effects on water consumption of sheep and goats

Water is one of the most important nutrients required for the maintenance of life, and it is involved in many physiological functions essential for performance of small ruminants. Water is essential for the adjustment of body temperature, growth, reproduction, lactation mechanisms, digestion pattern, nutrient exchanges and transport to and from cells in blood, excretion of waste products and heat balance (Ben Salem, 2010). Water requirements are regulated by dry matter intake (during drought, animals require more water as they are forced to select more fibrous and less digestible feed), environmental temperature (animals use more water for evaporative cooling in hot weather), and loss of water from body evaporation (body surfaces and the respiratory tract), urine, feces, and milk (Giger-Reverdin and Gihad, 1991). Unlike feed nutrients, water does not receive adequate consideration to ensure optimal performance of ruminant animals, mainly those raised under hot conditions.

Small ruminants may experience moderate to severe water restriction during a variety of commonly occurring environmental conditions (i.e., drought periods, shipment, when grazing in areas far from watering sources), and their requirements for water in dry areas are high due to high temperature and radiation load from the sun (Ben Salem, 2010). Sheep and goats are characterized by a remarkable tolerance to drought conditions. In general, goats are better at conserving water than sheep and possibly due to their browse diet (Silanikove, 2000 b; Dwyer, 2009; Silanikove and Koluman, 2015). Goat breeds differ in their capacity to cope with hot periods without water: Black Bedouin and Barmer goats can live on a once every four days watering regime (Khan et al., 1978; Silanikove, 1992); and Desert goats raised under traditional systems may be watered only once every three to six days, when water is scarce (Ahmed and El Kheir, 2004). In sheep breeds, variations in water deprivation tolerance are also observed; Awassi ewes can withstand more than 6-week period of watering every two days without significant changes, while watering once every four days causes important physiological changes (higher blood urea, creatinine, protein, globulin and cholesterol) accompanied by weight loss (Jaber et al., 2004); Yankasa sheep survived five days of water restriction but with several physiological changes (higher total protein, albumin, globulin and urea: Igbokwe, 1993); Desert Bighorn sheep withstood water deprivation up to five days (Turner, 1979), while Barki sheep in Egypt did not endure three days without drinking (Farid et al., 1979).

Overall, a water deprivation for three days or more would have detrimental effects on feed intake by ewes which exhibited reduced milk production, body weight, jaw movements during rumination, respiratory rates and increased rectal temperatures (Aganga et al., 1990). However, goats kept under HS conditions doubled their water consumption (Salama et al., 2012; Caulfield et al., 2014). Increased water intake was mainly used by HS goats for boosting heat loss by sweating and panting (Hamzaoui et al., 2013). In this regard, total water evaporation from water input was three times greater in the HS goats than the controlled ones (Hamzaoui et al., 2013). Insensible water loss by diffusion of water from the skin was two times higher at 35ºC than at 18ºC (Shafie et al., 1994). Furthermore, sheep consume 2 kg water/kg DM at temperatures between 0 and 15ºC, and this ratio increases three times at temperatures above 20ºC (Conrad, 1985). In addition, water consumption is 9–11% of the total body weight during winter and 19–25% during summer in sheep (Khan and Ghosh, 1989). Exposure of sheep to HS conditions induces a marked increase in water turnover (6% in winter and 7% in summer) and water intake (Khan and Ghosh, 1989; Ismail et al., 1995).

Heat stress effects on reproduction and fertility of sheep and goats

Extreme ambient temperatures are the major constraint to animal productivity. Summer HS is a major contributing factor to low fertility of domestic animals inseminated in the summer months (Hansen et al., 2001). Effects of HS on fertility is more pronounced in lactating animals because the large amounts of heat produced as a result of lactation make it difficult to regulate body temperature during HS (Hansen, 2009). Non-lactating animals and animals for meat purposes are much less likely to experience infertility during HS due to seasonal breeding patterns that ensure that animals are not bred at the warmest time of year, and relatively low amounts of metabolic heat production as compared to lactating animals (Hansen, 2009). In general, HS conditions drastically affect the sexual behavior, reduce the sexual activity and in turn reduce sperm quality resulting in poor conception (Dwyer, 2009). Thus, it is important to be aware of weather extremes during all reproductive stages. There are two mechanisms by which HS leads to infertility in animals (Hansen, 2009; Aggarwal and Upadhyay, 2013). The first mechanism is what actually causes reproductive problems through a direct effect of hyperthermia on the reproductive axis. The second mechanism is the indirect effect of HS on feed intake (decreased by HS) in order to reduce metabolic heat production leading to changes in energy balance and nutrient availability. These changes act via hypothalamic-hypophyseal axis and cause negative effects on reproductive performance (affecting reproductive cyclicity, pregnancy and fetal development). Most mammals have testes suspended in a scrotum outside the body cavity so that intratesticular temperature is slightly lower than core body temperature. In males, HS seriously affects fertility and reduces sexual desire by reducing testosterone level, sperm production and motility, and increasing proportion of morphologically abnormal spermatozoa, thus affecting semen quality (Hansen, 2009). Semen characteristics (ejaculate volume, semen pH, spermatic concentration, spermatic motility, sperm abnormalities) of rams and bucks are affected within days of exposure to HS, in which the alterations in semen occur about two weeks after HS and do not return to normal until up to six to ten weeks following the end of HS (Gimenez and Rodning, 2007). To avoid fertility problems during HS, the scrotal sack should be free from wool as the rams should be sheared six to eight weeks prior to breeding. In extreme circumstances, rams can be housed during the day and kept with the ewes at night (Gimenez and Rodning, 2007). In females, HS reduces fertility, ovulation, conception rate, expression of estrus, embryonic survival and fetal development (Ocfemia et al., 1993; Hansen, 2009). HS impairs follicular and oocyte development by altering progesterone, luteinizing and follicle-stimulating hormones' secretion and dynamics during the estrous cycle (Ozawa et al., 2005).

Methods for HS alleviation

From the above discussed sections, it could be concluded that the changes in the biological functions of sheep and goats due to exposure to HS include depression in feed intake, disturbance in the metabolism of water, protein, energy and mineral balances, enzymatic reactions, hormonal secretions and blood metabolites. Therefore, a variety of methods should be adopted by small ruminant producers/owners to overcome the negative effects of HS, including the use of shades, feeding and grazing strategies, providing water, handling time, the use of fans and evaporative cooling, and site selection of animals' housing (Morrison, 1983; Caulfield et al., 2014; Al-Dawood, 2015).

Shade is the easiest method to reduce the impact of high solar radiation, and it is applicable under extensive conditions. The minority of sheep and goat flocks are permanently housed, while most of them are housed only during the night and in periods in which grazing is not feasible (Kandemir et al., 2013). The use of shades, fans or evaporative cooling is not possible in semi-intensive systems as sheep and goats are grazed in the open during most of the day, and this necessitates other strategies (i.e. portable shades) to counteract the adverse effects of HS (Silanikove, 2010). Accessibility of animals to shade during summer is simple, easy, cheap and an efficient tool to minimize HS (Silanikove, 2000 a; Al-Tamimi, 2007). Providing sheep and goats access to shade leads to improvements in weight gain, milk production and reproductive performance (Berger et al., 2004), and allows a reduction in rectal temperature and respiration rate in goats (Hammadi et al., 2012). A well-designed shade structure reduces heat load by 30–50% (Muller et al., 1994). Shelters do not need to be complicated or elaborate, trees and shrubs can serve as shelters for animals from solar radiation (Onyewotu et al., 2003), and are usually the least-cost alternative. If natural shelter is not available, many sheep and goat producers use Quonset huts, plastic calf hutches, polydomes and/or carports to provide shelters for grazing animals. In addition, hay or straw shades, solid shade provided by sheet metal painted with white on top (Bond et al., 1961), and aluminum sheets (Bond et al., 1969) are the most effective and cheap materials.

Ration modifications can greatly help in reducing the negative effect of HS, and these adjustments may include changes in feeding schedules (feeding at cool hours, feeding intervals), grazing time, and ration composition such as dietary fiber adjustment, the use of high-quality fiber forage, increased energy density (supplemental protected fat) and use of feed additives (buffers [sodium bicarbonate], niacin, antioxidants and fungal culture [yeast culture]). During summer, the feeding behavior for most of the animals changes and they tend to consume more feed during the cooler periods of the day (West, 1999). Therefore, feeding animals during the cooler periods of the day encourages them to maintain their normal feed intake and prevents the co-occurrence of peak metabolic and climatic heat load (Mader and Davis, 2004). Also, feeding animals at more frequent intervals helps to minimize the diurnal fluctuation in ruminal metabolites and increase feed utilization efficiency in the rumen (Soto-Navarro et al., 2000). Another point to be taken into account to alleviate HS is the grazing time. In extreme heat, animals decrease their grazing time and spend more time in the shade, especially during the heat of the day. They graze during the period of the milder weather during the day, i.e. before sunrise, at dawn and during the night (Dwyer, 2009). Careful ration modifications during HS are important in achieving the optimum animal performance. Decreasing the forage to concentrate ratio can result in more digestible rations that may be consumed in greater amounts (Aggarwal and Upadhyay, 2013). Feed containing low fiber rations during hot weather is logical since heat production is highly associated with metabolism of acetate compared with propionate (Atrian and Shahryar, 2012). More nutrient-dense diets are usually preferred during the HS period (West, 1999). Dairy goats supplemented with 4% fat during summer had lower rectal temperature. Soybean oil fed to goats kept under HS increased milk fat content (Salama et al., 2012). Feed additives have been proposed to offset the consequence of HS. For example, antioxidants such as vitamin C and E protect the body defense system against excessive production of free radicals (antioxidants are free radical scavengers) during HS and stabilize the health status of the animal (Silanikove, 2010). Ayo et al. (2006) and Ghanem et al. (2008) found that vitamin C supplementations to sheep and goats are effective in alleviating HS.

Vitamin E and C supplementations decreased rectal temperature and respiration rate (Sivakumar et al., 2010), and alleviated HS in goats (Kobeisy, 1997).

One of the best practices to reduce HS is to provide adequate fresh and cool drinking water (Silanikove, 2000 a; Atrian and Shahryar, 2012). The water requirements of sheep and goats increase under HS conditions, thus, it is essential that animals have a continuous access to adequate, clean, cool and fresh water. This is done by having adequate watering devices (making sure pressure is adequate to refill waterers), and providing more water sources in the pasture (Atrian and Shahryar, 2012).

In addition, handling animals should be kept at minimum. Sheep and goats can be handled (i.e. milking, transportation) in the early morning or late evening time (Morrison, 1983), and the afternoon work should be avoided when body temperature is already high. One of the effective methods for prevention of HS is to delay afternoon milking for 1-2 hours (Atrian and Shahryar, 2012). Alteration of air temperature and velocity must be considered to alter the microclimate of an animal effectively (Da Silva, 2002). Poor ventilation has reduced the performance of sheep (Sevi et al., 2006). Also, it may be necessary to install fans or other cooling systems in barns and similar structures (Atrian and Shahryar, 2012; Sejian et al., 2015). Cooling sheep and goats by spraying could reduce HS symptoms and improve animal welfare (Salama et al., 2012). Direct wetting of animals is often used as an emergency measure and can be an effective protective method (Onyewotu et al., 2003). Sprayed and ventilated heat-stressed goats for 1 h/day consumed more feed (18%) and water (7%) and produced more milk (21%) (Darcan and Güney, 2008). The site selection of animals' housing is fundamental to decrease exposure and minimize the effect of HS. Proper selection of the housing site to emphasize factors for enhancing heat dissipation (minimal radiation, air temperature and humidity, and maximal air velocity) will have long-term protection benefits (Sejian et al., 2015). Thus, adequate space allowance, feces accumulation management and scrupulous monitoring in terms of temperature, relative humidity and air quality are crucial aspects in sheep and goat housing (Kandemir et al., 2013). In addition, fully enclosed shelters are not recommended for hot climates because of the decreased natural air velocity, therefore, it is preferred to use partially enclosed shelters (Sejian et al., 2015).

Conclusions

Livestock genetic improvement should take into account not only production traits (milk yield, weight gain and wool production), but also the interaction of those traits with the environmental factors (i.e. air temperature, relative humidity and solar radiation). HS exerts negative effects on productivity and well-being in small ruminants. The exposure of sheep and goats to HS negatively affects biological functions, changes antioxidant levels and various hormones which are reflected in the impairment of their health, production and reproduction. Sheep and goats show various responses to HS at behavioral, physiological, molecular/cellular, hematological, biochemical and immunological levels. HS adversely affects animals' comfort, water consumption, feed intake, milk yield and quality, meat quality, and reproduction and fertility. Thus, management strategies must be applied to counter hot/humid environmental conditions. Control is based on the provision of drinking water, adjustments in animals' diets during HS (such as increase in the energy density of rations, the use of feed additives, etc.), use of cooling mechanisms (shade and fans), the use of strategies to reduce the impact of HS on fertility (i.e. timed mating programs during summer), and scheduling animal activities in the early morning and evening when temperatures are not as extreme. For optimal results, the people who care for animals should have appropriate education and experience, understand the species requirements and have good observational skills. It is to be noted that awareness of HS is the first step towards its management. In addition, effective participation, coordination and active cooperation among scientists, technicians, meteorologists, veterinarians, nutritionists and local agricultural organizations are required to successfully include these factors as a basis for strategic and operational management decisions to improve production systems. There is a need to intensify agricultural extension staff/farmer relationships and researcher/agricultural extension staff linkage to improve farmers' knowledge, skills and practices on the use of HS management techniques. Finally, it is hoped that this review serves as guidance to researchers and contributes to ongoing efforts to promote HS management, and therefore will contribute to agricultural sustainability.

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Received: 4 VII 2016
Accepted: 20 X 2016