Review Article

Thermoregulation in Sheep and Goats: Review

Abstract

Thermoregulation is how mammals maintain their core internal temperature by returning the body to homeostasis. Sheep and goats are adaptable to different environmental changes and often perform better heat stress additivity compared to other ruminant animals. Adapting sheep and goats to extreme weather conditions occurs through behavioral, genetic, physiological, and morphological bases. They can minimize the adverse effects of thermal stress through behavioral responses such as increased water intake and shade seeking and other morphological mechanisms such as hair color and fat storage. Sheep and goats also respond to thermal changes through physiological mechanisms such as changes in the respiration rate, sweating rate, metabolic rate endocrine functions. In genetics, the authors report that animals can inherit traits that favor their survival in specific environmental conditions. The sheep or goat's size and shape determine the heat gain or loss rate and are crucial in adjusting water loss and heat gain in scorching environments. Goats and sheep exposed to high ambient temperature tend to have an elevated respiratory rate, pulse rate, and increased rectal temperature. Genetically, the adaptation of sheep and goats to different thermal environments is mediated by a complex network of genes with specific genome-wide DNA markers enhancing tolerance to heat stress.

Keywords: Thermoregulation, Sheep and Goats, Physiology, Behavior, Genetic, Heat stress

Introduction

Small ruminants, including sheep and goats, have been primarily kept in various environments and grazing systems, requiring multiple adaptations, especially concerning temperature changes through thermoregulation. From a biological perspective, thermoregulation can be defined as how mammals maintain their core internal temperature by returning the body to homeostasis. The influence of the thermal environment on animals is primarily exerted through energy exchange which involves convection, conduction radiation, and evaporation. Many animal factors (e.g., breed, genetics, health status, body condition, and coat color) determine metabolic intensity, the rate of thermal exchange, and thermal insulation, which contribute significantly to the heat balance of the animal. The optimal internal temperature ranges for different mammals are based on various factors, such as the temperature of the surrounding environment and energy requirements. Heat stress is one of the primary factors that can affect the growth of small ruminant animals such as sheep and goats in different parts of the world. As a limiting factor, excessive heat stress can lead to impaired production, reproduction, compromised natural immunity, and increased susceptibility to diseases. Heat stress affects ruminant animals through various environmental factors, including high ambient temperature, excessive solar radiation, relative humidity, wind, rainfall, and nutrition. However, sheep and goats are adaptable to different environmental changes and often perform better heat stress additivity compared to other ruminant animals. The current review explores the process of thermoregulation in sheep and goats. It describes the various physiological features of ruminant animals that enhance their ability to perform better stress additivity. The adaptation of sheep and goats to extreme weather conditions occurs through behavioral, genetic, physiological, and morphological bases. These mechanisms are divided into those that modulate heat production rates and the rate at which heat flows into and out of the organisms. From a morphological perspective, the coat color of the sheep or goat plays a vital role in the absorption of heat, with the light-colored coated animal absorbing less heat than those with darker coats.

Genetically, scientific evidence has shown that different genetic factors enable sheep and goats to live in heat-stressed environments. Other genes associated with adaptability to temperature changes have been found in sheep and goats, including HSP70, which are heat shock protein genes that protect the animals from heat stress, and the ENOX2 gene, which has been found in heat-stress susceptible goats. Other polymorphic genes, including MCIR, ASIP, and TYRP1, have been observed in different sheep breeds and are associated with wool color, which controls the rate of heat absorption. To this extent, therefore, it can be hypothesized that the adaptation of the ruminants to different environmental conditions is based on their ability to survive and reproduce under extreme living conditions.

Considering the lack of complete information on the adaptation and survival of these animals, the current review provides an integrative discussion on the various adaptative mechanisms of the ruminants in heat-stressed environments. It assesses the multiple genes that are involved in thermoregulation.

Literature Review

Different environmental conditions differently affect the productivity of livestock while also having an impact on various physiological parameters. Temperatures above the thermoneutral zone trigger a chain of physiological, anatomical, and behavioral changes in the animal's body, such as a reduction of feed intake, a decline in performance (milk production, growth, and reproduction), a decrease in activity, an increase of respiratory rate and body temperature, the addition of peripheral blood flow and sweating and change in endocrine function (Fuquay, 1981; Kadzere et al., 2002; Farooq et al., 2010; Renaudeau et al., 2012). Thermal stress affects the dynamic characteristics of digestion and neuroendocrine factors influencing metabolism. Declining feed intake has been identified as a significant cause of reduced milk production in livestock species (Farooq et al., 2010). Various research studies have investigated the relationship between ecological changes and animal response. However, quite limited extensive research has been conducted to determine how sheep and goats respond to temperature changes through thermoregulatory processes. According to a research study by Leite et al. (2017), livestock tends to show reduced productivity levels in environments with high levels of thermal radiation due to changes in their physiological processes. As expected, animals often develop adaptive features to cope with environmental changes to guarantee survival. In their research study, Leite et al. (2017) highlight hair characteristics as one of the features directly associated with heat exchanges with the environment. According to Leite et al. (2017), the hair structure serves two primary roles: protecting the skin from direct solar radiation and promoting the processes of convection and heat loss through evaporation. The efficiency of the performance of these roles is entirely dependent on the physical structure of the hair coat. Therefore, the form of the hair coat is considered a prominent physical thermoregulatory feature of livestock, especially in sheep and goats.

Berihulay et al. (2019) conducted a review to investigate the adaptation of small ruminants, specifically sheep and goats, to environmental heat stress. According to the study, sheep and goats are among the livestock that can quickly adapt to changes in environmental temperature through a combination of physiology, morphology, and genetic makeup (Berihulay et al., 2019). The review notes that sheep and goats can minimize the adverse effects of thermal stress through behavioral responses such as increased water intake and shade seeking as well as other morphological mechanisms such as hair color and the amount of fat they keep (Berihulay et al., 2019). Other physiological changes involved the reduction of the basal metabolic rate, modifications in the acid-base balance, and hormonal balance changes (Farooq et al., 2010; Renaudeau et al., 2012). Heat stress significantly induces the secretion of hormones connected with metabolism (thyroxine, somatotropin, and glucocorticoids) and water balance (antidiuretic hormone and aldosterone). Several days after heat stress begins, the secretion rate of thyroid hormones is reduced. Growth hormone secretion rates are reduced during prolonged heat stress after an initial rise (Farooq et al., 2010). Adrenal corticoids, mainly cortisol, immediate physiological changes that allow animals to undergo stressful conditions (Hansen, 2004; Beatty et al., 2006; Renaudeau et al., 2012). Therefore, thermoregulation is part of a homeostatic mechanism to keep the organism at an optimum operating temperature within certain boundaries, even when the surrounding temperature is very different (Ruben, 1995; Grigg et al., 2004). In terms of physiology, Berihulay et al. (2019) report that sheep and goats respond to thermal changes through changes in the respiration rate, sweating rate, metabolic rate endocrine functions. Regarding genetics, the authors report that animals can inherit traits that favor their survival in specific environmental conditions (Berihulay et al., 2019). The authors note that sheep and goats are rustic animals that can easily cope with different environments and are less susceptible to heat-stressed environments than other ruminants.

Morphological Thermoregulation in Sheep and Goats

Morphological thermoregulation in sheep and goats occurs through physical changes that enhance their fitness in their operational environment. According to Berihulay et al. (2019), the central morphological adaptations of sheep and goats to differences in thermal conditions include body size and shape, coat and skin color, hair type, and fat storage. To be specific, Leite et al. (2017) mention different breeds of sheep and goats that uses the mentioned adaptations to survive in thermally stressed conditions. According to Leite et al. (2017), the Sudanese Saleh and Egyptian Zaraiby goats have long legs and ears as a thermoregulatory morphological adaptation, while West African goats have short legs. The authors report that the Awassi sheep have loose coarse wool and adipose tissue reserves as a thermoregulatory morphological adaptation to heat changes in their environment.

In contrast, the Damar sheep have fat tails. On the other hand, Massese, Xalda, and Soay sheep use coat color as the thermoregulatory morphological adaptive feature, during Barki sheep and goat use skin pigmentation. Therefore, Berihulay et al. (2019); Leite et al. (2017) reported that sheep and goats have different thermoregulatory morphological adaptive features such as body size and shape, coat and skin color, hair type, and fat storage. An animal's body size and shape is a dominant morphological feature that influences the thermoregulatory mechanisms of sheep and goats in scorching environments. According to Joy et al. (2020), the size and shape of the sheep or goat determine the heat gain or loss rate and can be crucial in adjusting water loss and heat gain in scorching environments.

Biologically, any animal with larger body size is expected to have a reduced metabolic rate and gain heat slower than smaller animals (Berihulay et al., 2019). As such, sheep and goats in scorching environments are expected to have a larger body size to reduce the rate of metabolism and heat absorption. Also, as reported by Joy et al. (2020), taller animals are expected to release more heat compared to short and squat-bodied animals, which explains why the Sudanese Saleh and Egyptian Zaraiby goats have long legs and ears as thermoregulatory morphological adaptive features for evaporative heat loss. In terms of fat storage, Berihulay et al. (2019) report that one-quarter of the global sheep population are fat-tailed breeds and are extensively in tropical environmental conditions, and can accumulate and mobilize the body fat in the internal fat depots. It is important to note that sheep and goats use fat tails and fat rumps as a thermoregulatory morphological feature based on their operational environmental condition. Therefore, body size, shape, and fat storage are important thermoregulatory morphological features and mechanisms for sheep and goats. It is thought that the evolution of subcutaneous (fatty tissue) or supercutaneous (hair) thermal insulation affects heat flow to and from the organism along the thermal gradient from the organism to the environment (Schmidt - Nielsen, 1997; Bligh, 1998). This implies that sheep fleece morphology affects heat dissipation from their skin surface through thermoregulatory mechanisms.

The sheep's coat morphology changed significantly during domestication. There are primitive sheep breeds that still possess a double coat of coarse outer hairs (produced by primary hair follicles) and fine inner hairs (derived from secondary hair follicles), like Soay sheep. Rather than having two follicles, modern wooled sheep (e.g., Merino) have a single coat containing both primary and secondary follicles (Sumner and Bigham, 1993, Galbraith, 2010). However, there is a wide variation in skin and coat morphology across different body regions. Skin thickness decreases from dorsally to ventrally on the trunk and from proximally to distally on the limbs (Scott, 1988).

There is a positive correlation between skin thickness, mean fiber diameter, and staple length (Gregory, 1982). Among sheep, the pinnae and the axillary, inguinal, and perianal regions have the thinnest skin, with an average thickness of 2.6 mm in adults (Lyne and Hollis, 1968). These areas with thinner skin and shorter hair act as "thermal windows" for the dissipation of heat (Fowler, 1994; Mauck et al., 2003). Infrared electromagnetic waves can measure the flow of thermal energy between the skin and the environment. For detecting this infrared radiation in the boundary layer of an animal, infrared thermography is an excellent non-invasive tool (Gerken, 2010; AL-Ramamneh et al., 2012).

According to Berihulay et al. (2019), coat and skin color are critical morphological features used for thermoregulation by different animals, including sheep and goats. The characteristics of the coat and skin of sheep and goats in tropical and desert environmental conditions are entirely different from those in temperate environments (Joy et al., 2020). A hair coat's ability to absorb radiant heat depends on its surface area, pigmentation, structure, length, and condition. Several studies have shown that black-pigmented hair in strong sunshine has a greater surface temperature than hair with other colors, whether in sheep or goats. The coat color is an important feature that determines the radiant heat load and the amount of solar radiation that is reflected and absorbed by the animal. Those with light coat coloring absorb less heat than those with dark coat coloring (Berihulay et al., 2019). According to Leite et al. (2017), sheep with dark pigments are more prone to areas with heat stress than those with light pigmentation. The coloration of surfaces is caused by differential reflection or transmission of shortwave radiation. Sensible heat is generated whenever the surface doesn't reflect or transmit the radiation (Walsberg, 1983; Gerken, 2010). A darker coat color absorbs solar radiation more efficiently, providing more heat and emitting more energy (Galvan and Solano, 2016).

Consequently, animals adapted to hot climates have been observed to change their hair coat colors to alter their solar absorption (Acharya et al., 1995; Kadzere et al., 2002). Therefore, selecting animals with a light color is essential for the welfare and production efficiency of the sheep. According to the review by Berihulay et al. (2019), the effects of coat coloring that are related to climatic-stress-tolerance traits in the west African dwarf sheep include the rate of respiration, the rectal temperature, the pulse rate packed red cell volume (PRCV), plasma sodium (Na+), and potassium (K+). It has also been reported that sheep with carpet-type wool, thinner skin, and shorter hairs are well adapted to hot environments due to the improved heat dissipation rate (Berihulay et al., 2019). Therefore, coat and skin color are essential thermoregulatory morphological features used by sheep and goats to survive in different thermal environments.

Behavioral and Physiological Mechanisms of Thermoregulation

The behavioral adaptation of sheep and goats to different environments is based on their instinctive reaction to changes in their external environment by performing various activities to control their body temperature. According to Berihulay et al. (2019), the behavioral adaptation of small ruminants is meant to protect themselves from extreme environmental factors through the shedding of hair, water restriction, and control of feed intake. Also, it is essential to note that ruminants are active during the day and rest during the night to control the amount of heat and energy requirements based on their operation environment (Okoruwa, 2014). When small ruminants like sheep and goats have exposed to excessively high-temperature conditions, there shall be a reduced intake of feed as a means of adaptation to reduce heat production since the heat increment of feeding is a crucial source of heat production. According to Joy et al. (2020), goats are better adapted to heat stress than other ruminants because they have a dynamic eating behavior in hot environmental conditions. For example, the Saanen goats exposed to highly severe heat stress have a larger meal size but a reduced number of meals compared to the German Improved Fawn (GIF) goats (Berihulay et al., 2019). Goats exposed to highly stressful conditions have a reduced feed intake, body weight, and growth rate to maintain their thermoregulatory mechanisms and average body temperature.

Goats and sheep possess various physiological thermoregulatory mechanisms to adapt to different environmental conditions. When the physiological mechanisms of the animals fail to address the effect of various heat changes, the body temperature can change to a point where its well-being is compromised (Berihulay et al., 2019). The body temperature of an animal is essential in gauging its heat tolerance as it represents the net amount of heat as a result of the heat gain and loss processes in the body. The critical physiological adaptation mechanisms in small ruminants, including sheep and goats, include the change in heart rate, respiration rate, and rectal temperature. The rectal temperature of sheep and goats is a standard tool of measurement of the body temperature, even if there is a significant variation in the temperature of other body parts at various times of the day. In areas of high heat stress, the respiratory rate is the primary thermoregulatory mechanism used by sheep and goats to maintain an average body temperature. Another physiological thermoregulatory mechanism sheep and goats use is panting, resulting from an increased respiratory rate (Berihulay et al., 2019). It is important to note that sheep and goats experience various complex physiological changes in response to varying changes in temperature. In most cases, animals exposed to high ambient temperatures tend to have an elevated respiratory rate, pulse rate, and increased rectal temperature. Therefore, physiological mechanisms are necessary for the thermoregulatory adaptations of sheep and goats to different environments.

As aforementioned, Berihulay et al. (2019) reported that the physiological adaptation of sheep and goats in a heat-stressed environment occurs through an increased respiratory rate, increased sweating rate, reduced metabolic rate, and changes in the functioning of the endocrine system. Various research studies and literature have shown that the respiratory rate and the rectal temperature are good indicators of thermal stress and can effectively assess the adversity of the operational thermal environment. According to Gupta et al. (2013), an increase in the rectal temperature of goats from 38^0 to 39^0 indicates that the animal has been kept at a hot ambient temperature for more than six hours. Another research study by Al-Dawood (2017) reported that an increase in rectal temperature above 44^0C indicates that the animal has been exposed to higher temperatures. According to Al-Dawood (2017), the respiration rate of goats increases significantly at a temperature above 40^0C, and ewes also report significant increases in the respiratory rate and rectal temperature when subjected to walking stress of more than 14km in a day which increases their body temperatures. An increase in the temperature of sheep and goats above the thermal comfort leads to the activation of evaporative cooling mechanisms, and the rate of sensible heat loss gets reduced (Berihulay et al., 2019). Therefore, the respiratory rate and rectal temperature can be considered critical physiological indicators of the thermal conditions of the environment.

Genetic Mechanisms of Thermoregulation

Performance traits are antagonistic with heat tolerance and, therefore, the use of heat-resistant individuals in goat breeding programs should be one of the main strategies to improve both animal welfare and productivity in hot climates

Adaptation concerning genetic aspects is associated with the inheritable traits of animal characteristics or features that enhance their survival or tolerance to their external environment. In most cases, adaptive features are characterized by reduced heritability with the genetic variation within a population, providing the flexibility of adaptation to various environments, which is crucial for the population's long-term survival. Research studies and literature have indicated that genes' role in determining the capability of sheep and goats to survive in a heat-stress environment is complicated mainly because the mitochondrial genes have a high association with adaptability to temperature changes as it plays a central role in energy metabolism. Most organelles in small ruminants like sheep and goats have a specific genome with one particular modified genetic code, with the mitochondrial genome being a circular and double-stranded molecule. Some outstanding characteristics of the mitochondrial DNA that play a role in thermal regulation include the relatively conservative gene content and organization, the reduced size, and the limited recombination. As Berihulay et al. (2019) reported, the adaptation of sheep and goats to different thermal environments is mediated by a complex network of genes with specific genome-wide DNA markers enhancing tolerance to heat stress, as is the case in the case of Egypt Baraki desert sheep and goats. Some possible genes that play a role in heat tolerance in sheep and goats include ANXA6, GPX3, GPX7, and PTGS2. Therefore, genes play a critical role in thermoregulation in sheep and goats.

Endocrine and Metabolic Thermoregulatory Adaptation

Heat stress generally affects livestock productivity, but very little information is available regarding their response to heat at a cellular level. Stress affects both innate and adaptive immune responses in animals. The immune system does not respond directly to stress but acts via the neuroendocrine system. The stress-related hormones act on the immune cell receptors to modulate the immune response. The innate immune response is one of the primary immune responses that help tackle the pathogens that enter the host animals. According to Roach et al. (2005), most vertebrate genomes contain one gene for each of the six major TLR families (TLR1, TLR3, TLR4, TLR5, TLR7, and TLR11). The heat shock response confers transient thermal tolerance, partly due to the expression of heat shock proteins (HSPs). HSP70 plays the most dominant role among all the HSPs in protecting cells from damage caused by acute thermal stress (Dangi et al., 2014). Several kinds of the literature showed that heat shock proteins (HSPs) are rapidly synthesized in tissues subjected to thermal stressors.

In living tissues, HSP maintains the integrity of structural proteins, prevents protein aggregation, and aids the folding–refolding of damaged proteins (Morimoto, 1998b, 2008). Hsp90 is necessary for the viability of eukaryotes. It has been proved that Hsp90 direct folding, structural integrity, and proper regulation of a subset of cytosolic proteins (Carver et al., 1994; Matsumiya et al.,2009; Nguyen et al., 2009; Te et al., 2007). Besides, a decrease in intracellular Hsp90 concentration has been reported to increase the mortality of mammalian cells at high temperatures (Barnes et al., 2001). Hsp60 is believed to protect the structure and function of native macromolecules, particularly as they traffic across membranes (Gupta et al., 2010).

The plasma cortisol concentration in the blood determines the endocrine adaptation of sheep and goats to different thermal environments. According to Archana et al. (2018), the Salem Black goats have reduced plasma cortisol concentrations, which indicates their superiority in adaptability to stressful conditions compared to the Osmanabadi goats, with a relatively high concentration of plasma cortisol in their blood during the summer. The plasma T3/T4 concentrations also determine the variations in the breeds of sheep and goats with their response to different heat conditions. According to Joy et al. (2020), the cross-bred Chokla sheep have high plasma T3 concentrations during the summer compared to other pure breeds, which indicates aberrant thyroid gland activity and poor thermoregulation in heat-stressed environments. Joy et al. (2020) further report that sheep breeds with low plasma thyroid hormone concentrations are more adapted to heat-stressed environments as a result of the reduction in the rate of production of metabolic heat. It is further reported that heat stress significantly increased the concentrations of plasma growth hormones in various goat breeds, including Osmanabadi, Salem Black, and Malabari. The Osmanabadi goats have higher plasma concentrations associated with increased thermotolerance to excessively heat-stressed environments. Therefore, the endocrine system plays a crucial role in thermoregulation in sheep and goats.

Regarding metabolism, the size of sheep and goats often determines the natural selection for the genotypes of adaptability to different environments. According to Joy et al. (2020), metabolism is a crucial determinant of thermoregulation which determines the net temperature of the animal. Sheep and goats with relatively small sizes have reduced metabolic requirements and reduced heat production, which helps them to survive in heat-stressed environments. The reduced size of sheep and goats often confers an advantage to the tropical breeds, ensuring their survival in such environmental conditions. Also, another important determinant of the amount of heat in ruminants is the volatile fatty acids profiles in the rumen, which are important determinants of energy supply in the animals. The fatty acids determine the amount of heat gained or lost which determines the animal's net temperature (Joy et al., 2020). According to Pragna et al. (2018), the Salem goat breeds have a higher propionate production than the Osmanabadi and Malabari, leading to reduced methane synthesis. Also, the differences in the concentration of the proportion of volatile fatty acids determine the digestibility of diets and the population of rumen microbes in goats exposed to heat stress challenges (Pragna et al., 2018). Therefore, metabolic activities in sheep and goats are important determinants of the temperature of the animals and their response to different thermal environments.

Conclusions

The current review explored the processes of thermoregulation in sheep and goats and described the various physiological features of the ruminant animals that enhance their ability to perform better stress additivity. Numerous studies have investigated the relationship between environmental changes and animal response. However, quite limited extensive research has been conducted to determine how sheep and goats respond to temperature changes through thermoregulatory processes. According to the review, heat stress is one of the primary factors that can affect the growth of small ruminant animals such as sheep and goats and can lead to impaired production, reproduction, compromised natural immunity, and increased susceptibility to diseases. The article further reports that the adaptation of sheep and goats to different thermal conditions occurs through behavioral, genetic, physiological, and morphological bases. Morphologically, the coat color of the sheep or goat plays an essential role in the absorption of heat, with the light-colored coated animal absorbing less heat as compared to those with darker coats. The behavioral adaptation of sheep and goats to different environments is based on their instinctive reaction to changes in their external environment by performing various activities to control their body temperature. Sheep and goats use fat tails and fat rumps as a thermoregulatory morphological features based on their operational environmental conditions. Also, sheep and goats exposed to high ambient temperature tend to have an elevated respiratory rate, pulse rate, and increased rectal temperature. Therefore, thermoregulation in sheep and goats occurs through behavioral, genetic, physiological, and morphological bases.

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