

Environmental Stressors and Productivity of Small Ruminants in Arid and Semi-Arid Regions: Physiological, Behavioral, and Health Responses

Kobra Poursad-Astamal¹ | Nemat Hedayat^{2*} | Vahid Vahedi³ | Reza Seyedsharifi² | Hussein Tanveer⁴

¹ Central laboratory expert, University of Mohaghegh Ardabili, Ardabil, Iran

² Department of Animal Science, Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran

³ Department of Animal Science, Moghan College of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran

⁴ Department of Molecular Biology, Virtual University of Pakistan, Lahore, Punjab, Pakistan

*Corresponding Author E-mail: hedayatuma@gmail.com

Submitted: 2025-07-20, Revised: 2025-08-04, Accepted: 2025-09-08

Abstract

Small ruminants such as sheep and goats are essential for the livelihoods of pastoral and agro-pastoral communities in arid and semi-arid regions, particularly in North Africa, the Middle East, and parts of South Asia. However, these animals are frequently exposed to harsh environmental conditions, including heat stress, water scarcity, poor feed quality, cold spells, and parasitic infestations. These stressors, individually or in combination, negatively impact animal health, productivity, and welfare. This review synthesizes recent findings on the physiological, behavioral, and immunological responses of small ruminants to major environmental stressors. The study places special emphasis on cumulative multi-stressor exposure and evaluates adaptation mechanisms in native breeds. Mitigation strategies such as nutritional interventions, water access, environmental modifications, and genetic selection are also reviewed. Heat stress disrupts feed intake and metabolism; water deprivation impairs thermoregulation and homeostasis; poor nutrition causes energy deficits and reproductive issues; cold stress and parasites further compromise immune resilience. Indigenous breeds display superior adaptability through evolved metabolic and behavioral responses. Practical mitigation approaches can alleviate these stress impacts and improve productivity in vulnerable regions. Understanding how small ruminants respond to environmental stress is critical for developing resilient livestock systems. Integrative strategies that combine improved management, environmental design, and genetic selection can enhance animal performance and ensure food security in climate-vulnerable areas.

Keywords: Harsh environments, Stress events, Small ruminants, Adaptation, Animal productivity, Climate change.

Introduction

When animals are exposed to adverse environmental conditions, stress can lead to numerous unfavorable consequences, ranging from discomfort to illness and even death [1]. Stress negatively affects animal life, impacting growth performance, productivity, and longevity, as well as the overall production status. Many stressors occur when animals are raised in extensive environments, such as rangelands and farm fields. Among them, malnutrition or undernutrition triggered by extreme conditions—such as high heat and radiation, low water availability and dehydration, and cold winds—plays a major role in reducing both the quantity and quality of animal feed intake [2]. The more intense the stressors, the more difficult it becomes for animals to recover. All these stressors can induce oxidative stress, which arises when there is an imbalance between pro-oxidant and antioxidant systems in the body. In small ruminants, such imbalance leads to the overproduction of reactive oxygen species (ROS), which can damage lipids, proteins, and DNA. This oxidative damage impairs key physiological functions, including immune responses, reproductive efficiency, and metabolic performance, thereby reducing overall animal health and productivity. Recent reviews have highlighted how variations in diet quality and quantity can modulate oxidative stress and antioxidant capacity in farm animals, directly influencing their productive traits. Over centuries, natural selection has enabled animals in these regions to adapt through behavioral and metabolic responses; however, such adaptations often come at the cost of reduced reproduction and productivity [2-4]. Native sheep and goats are the predominant livestock in regions with harsh climates. Recognizing and mitigating the effects of environmental stressors can enhance the performance

of animals raised in such areas. Water and feed availability should be prioritized as primary environmental stressors, alongside other climatic factors such as temperature, relative humidity, air velocity, solar radiation, and light. Ultimately, the genetic value of animals, nutritional management, and ecological conditions are the three main pillars influencing livestock productivity. By implementing effective stress mitigation strategies, it is possible to significantly improve the health, performance, and welfare of small ruminants under challenging environmental conditions.

Stress and response to it

Farm animals require suitable environmental conditions—including thermal, nutritional, water, and management factors—for optimal production. This requirement varies depending on the species, breed, age, production level, and physiological condition. The energy and other nutrients taken into the animal's body are allocated toward maintenance, growth, production, and reproduction [5]. The most critical priority is maintenance; any factor that significantly increases the maintenance requirement is defined as a stressor [6]. Environmental stressors not only reduce productivity and health in livestock, but also result in significant economic losses [2].

The stress response in animals comprises three basic stages: stress perception, biological defense, and the physiological or pathological consequences of that defense [7]. The response begins with the central nervous system (CNS) detecting environmental threats. Once the CNS perceives stress, it initiates physiological defense mechanisms that involve a sequence of behavioral, autonomic, neuroendocrine, and immune responses. Behavioral

responses—such as shade-seeking or fleeing from predators—are the first line of defense and serve to immediately mitigate the effects of external stressors [4]. The autonomic nervous system rapidly modulates heart rate, blood pressure, digestive activity, and adrenal medulla secretion. These effects are short-term and generally reversible, posing minimal long-term harm to the animal [8].

In contrast, neuroendocrine responses mediated by the hypothalamic-pituitary-adrenal (HPA) axis involve the secretion of glucocorticoids (mainly cortisol and corticosterone), which have more sustained and systemic impacts. Stress also influences other endocrine pathways by affecting the release of growth hormone, prolactin, follicle-stimulating hormone (FSH), luteinizing hormone (LH), and thyroid-stimulating hormone (TSH) [9]. These hormonal changes orchestrate metabolic adjustments essential for stress adaptation [10].

Interestingly, differences between sheep and goats in the magnitude and regulation of neuroendocrine responses have been reported. For example, goats tend to exhibit more stable cortisol levels under prolonged heat and dehydration stress, possibly reflecting a more robust HPA axis regulation. However, sheep may

show more pronounced physiological disturbances under the same conditions, indicating species-specific resilience mechanisms. Moreover, measurement techniques (*e.g.*, cortisol levels in wool, plasma, or saliva) often yield inconsistent results across studies and species. This variation underscores the need for standardized and comparative methodologies to better interpret physiological stress markers. When neuroendocrine regulation is insufficient to restore homeostasis, immune responses are activated. Stress-induced biochemical changes include shifts in amino acid profiles, hormone secretion patterns, and cytokine production [11]. These responses help re-establish internal balance, although they can also trigger harmful consequences. For instance, pro-inflammatory cytokines such as TNF- α increase rapidly under stress; while they aim to support recovery, they may concurrently induce oxidative damage and tissue inflammation [12]. Prolonged cytokine activity can lead to excessive free radical production (ROS and RNS), disrupting key metabolic pathways such as pancreatic insulin secretion, and further compromising animal health and productivity [13].

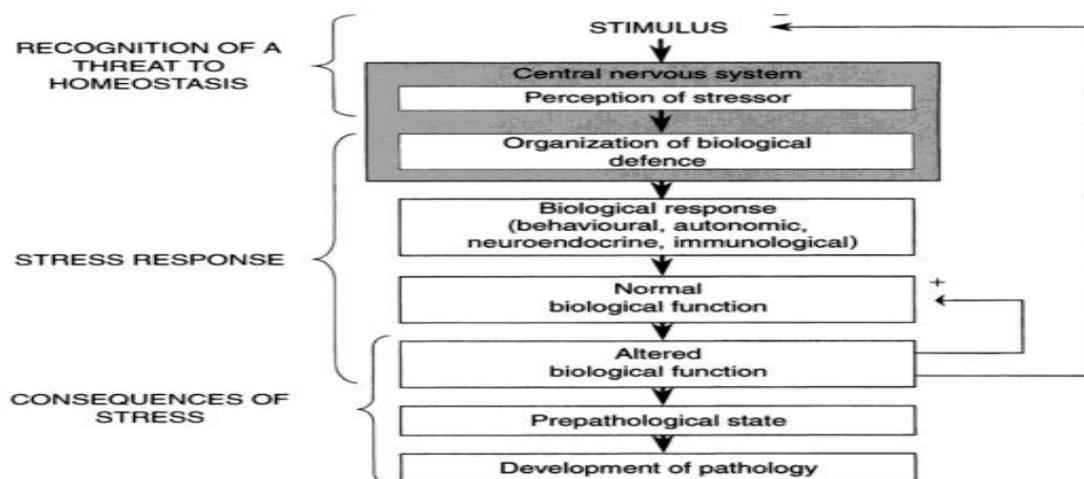


Figure 1 Steps of stress response, adapted from biological response to stress: the key to assessment of animal well-being [7]

Model of Biological Responses in Animals Under Stress

The degree of success in maintaining homeostasis depends on the intensity and number of environmental stresses [2,14,15]. The energy required to cope with multiple environmental stresses is high, and only by utilizing a portion of the body's reserves can the stress be alleviated (Figure 1). In cases of severe or multiple stress, using reserves alone will not be sufficient, and the production/weight ratio will decrease to compensate for the energy required to adapt to it [2]. At this stage, energy is transferred from active tissues involved in growth and lactation to vital tissues, including the brain, central nervous system, placenta, and fetus [5]. Adipose tissue is placed at the end of the priority list due to its late maturity and the fact that accumulating substances in it requires a significant excess of resources. As a result of these changes, the natural biological functions are altered, and the animal (or human) progresses through the pre-pathological and ultimately pathological stages, increasing its susceptibility to diseases in the surrounding environment [9].

Most Common Environmental Stresses

Thermal Stress

The comfort zone can vary depending on several factors, including animal type, species, breed, age, body coverage, production level, access to shade, nutrition, health status, and the overall management system [2,4,16-19]. Although both extremely low and high temperatures are harmful, heat stress poses a particularly significant challenge in arid and semi-arid regions. The impacts of climate change are expected to exacerbate thermal stress, thereby limiting the productivity of small ruminants [2]. In response to such conditions, animals activate various physiological and behavioral adaptive mechanisms, which require additional energy and may disrupt normal metabolic function [4,20]. Failure to cope with such stress can even result in mortality. However, discrepancies exist in how this relationship is modeled, and several equations have been developed to assess their interaction. A THI above 72 is generally considered the threshold for heat stress in cattle [17].

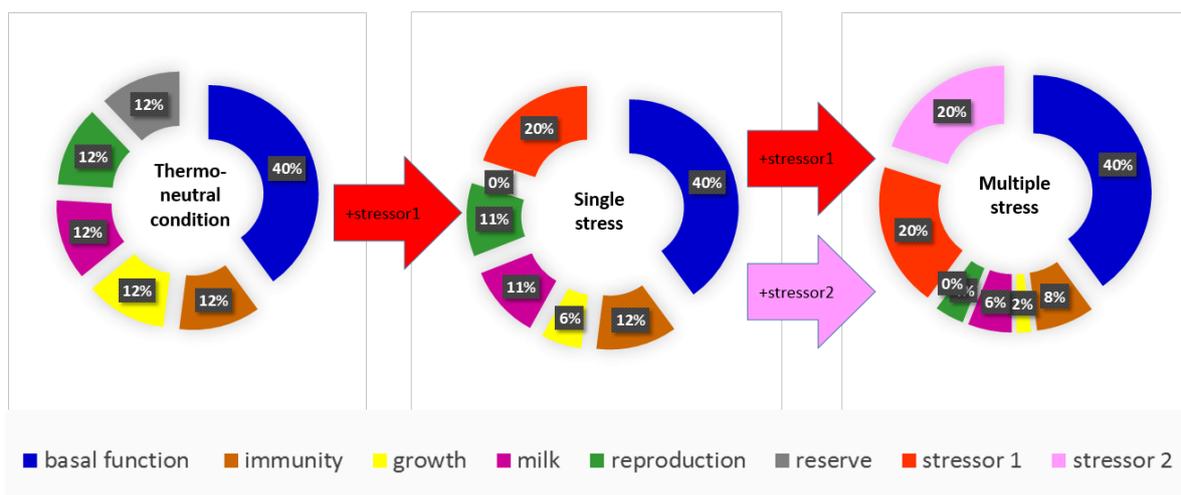


Figure 2 A schematic representation of the effect of (adapted and modified by Sejian et al. [4])

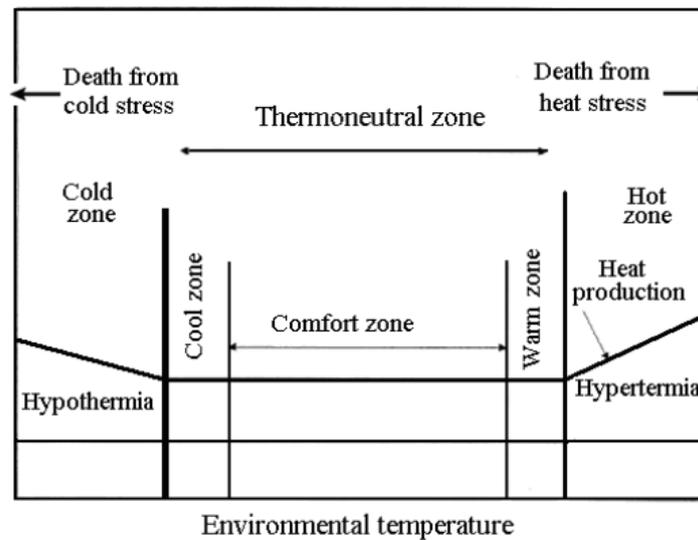


Figure 3 Comfort zone, hot and cold stress, and the death of animals

However, due to the distinct body characteristics and wool coverage in sheep, cattle-based THI formulas are inappropriate. Therefore, a specific equation has been proposed for sheep [19]:

$$\text{THI} = \text{db } ^\circ\text{C} - \{(0.31 - 0.31 \text{ RH}) (\text{db } ^\circ\text{C} - 14.4)\} \quad (1)$$

The values below 22.19 indicate no heat stress; 22.20–23.22 indicate moderate stress; 23.23–25.59 suggest severe stress; and values above 25.60 represent extreme heat stress.

Sheep are generally considered more sensitive to heat stress than cattle, partly due to their dense wool cover and limited capacity for evaporative cooling through sweating [19,21]. However, this general sensitivity varies significantly by breed. Indigenous sheep breeds in arid and semi-arid regions—such as those in North Africa, the Middle East, and Central Asia—have evolved remarkable adaptive traits, including efficient thermoregulation, lower metabolic heat production, specialized coat insulation, and behavioral strategies that enhance their resilience to heat stress [21]. These breed-specific adaptations explain why native sheep can outperform exotic or

commercial breeds under harsh thermal conditions, despite the overall species-level sensitivity to heat.

Effect of heat stress

Typically, animals remove the heat produced by the body through the mechanisms of conduction, convection, radiation, and evaporation (sweating and evaporation of the respiratory system) [4,19,20,22]. In the thermal comfort zone, three primary mechanisms maintain the balance between the environment and the animal's body [23]. During heat stress, evaporation through the respiratory system reduces the effects of high temperatures in the environment [4,24].

Typically, the respiratory rate (RR) in the thermal comfort zone ranges from 25 to 40 breaths per minute, and the rectal temperature (RT) is approximately 38.3 °C [25]. High environmental temperatures, such as those found in summer, cause an increase in rectal temperature and the rate of respiration because energy dissipation pathways are weakened [26]. On the threshold of heat stress, dairy cows increase their RR to 60 breaths per minute and RT to more than 38.5 degrees; milk production and

reproductive indicators also face a drop. In mild to moderate heat stress, the RR reaches 75, and the RT reaches 39. Moderate to severe thermal stress brings them to 85 and 40, respectively. In severe thermal stress, the RT exceeds 41 degrees, and the RR is around 120 to 140 breaths per minute [27]. In extreme heat stress, it reaches 200-300 breaths per minute in cattle and sheep [25], and an RT more than 42 degrees is lethal [20]. At high temperatures (at 35 °C), due to the lower effect of conduction and radiation mechanisms, the respiratory system is also responsible for the significant function of heat removal, approximately up to 60% [19] to 85% [28]. The hypothalamic center firmly controls RT, and a slight increase in it, especially during hot hours of the day, is an adaptation mechanism to reduce the RR during hot hours of the day to dispose of heat through radiation and conduction in cooler hours [29]. The heart rate (HR) may increase at high temperatures to enhance heat loss from the body. However, when the thermal load imposed on the animal rises too much, the heart rate also decreases because the metabolic rate of the body decreases significantly in extreme heat [19]. The decrease in dry matter consumption of animals exposed to heat stress occurs as a way to reduce body heat production [20,30,31]. The exposure of the animal to high environmental temperatures stimulates the environmental thermoreceptors to transmit suppressive nerve messages to the appetite center in the hypothalamus. By reducing feed consumption, fewer substrates are available for enzyme activities, and heat production is reduced. The reduction is more pronounced in fiber than in concentrate diets due to the higher heat increment (HI) [19]. Therefore, it is recommended to be more careful in feeding low-quality roughage to animals in summer [32]. Additionally, water

consumption increases in hot weather, which causes digestive tract to fill and also reduces the ability to consume feed [33]. On the other hand, heat stress reduces blood flow to internal organs, including the digestive system, and with increasing storage time, the ability to consume feed decreases. A reduction in feed consumption and an increase in the need for maintenance in heat stress conditions cause a decrease in energy, protein, minerals, and vitamins available for growth, resulting in a decrease in the final weight, average daily gain (ADG) of animals [33,34], and milk production faces a decrease [31,34,35]. In general, an increase in ambient temperature leads to a decrease in anabolism and an increase in catabolism due to a reduction in the level of feed consumed, a rise in hormones such as glucocorticoids and catecholamines, and a decrease in leptin [36]. Heat stress can decrease blood glucose primarily due to reduced feed intake [37,38]. However, some studies report an increase in glucose levels under heat stress, which appears contradictory at first glance. This discrepancy can be explained by differentiating between acute and chronic phases of heat stress. During acute heat stress, activation of the sympathetic nervous system leads to the release of catecholamines such as epinephrine and norepinephrine, which stimulate hepatic gluconeogenesis and glycogenolysis, temporarily increasing blood glucose levels despite reduced intake [26]. In contrast, prolonged or chronic heat stress results in sustained anorexia, energy depletion, and a decline in metabolic function, ultimately causing blood glucose levels to drop [37-40].

This temporal hypothesis reconciles findings across studies and reflects how animals shift their metabolic responses depending on the duration and severity of heat stress. Acute responses prioritize immediate survival through the mobilization of energy reserves, while

chronic exposure leads to energy conservation and catabolic states. These changes also align with hormonal adjustments—initially increased cortisol and catecholamines, followed by their eventual decline or altered partitioning under prolonged stress [39-41]. When animals are exposed to heat stress, feed intake decreases and metabolism slows down, causing thyroid gland function to decrease [2,42]. Although DMI decreased in heat-stressed cows, insulin concentration and responsiveness increased, an adaptive mechanism to overcome the situation and minimize the damage caused by heat stress [31]. However, prolonged heat stress lessens the level of insulin due to the sharp decrease in DMI [19].

Significant increases in urea and creatinine can be due to the decrease in blood supply to the kidneys (to support the growth in surface blood supply), although in some studies, creatinine can decrease [33]. In severe heat stress, excretion of K^+ in sweat increase, which causes a lower level of aldosterone, leading to an increase in urine output, and a sharp enhancement in plasma ADH concentration prevents water loss from the kidneys [43]. NEFA and ketone body levels in heat-stressed ruminants are highly dependent on insulin levels, and higher insulin levels decrease NEFA due to their anabolic activity. Limiting adipose tissue mobilization in heat-stressed animals is essential to utilize glucose to maintain milk or skeletal muscle synthesis [43].

A higher level of glucocorticoids is associated with a lower level of GnRH secretion, which causes a decrease in LH and FSH. Since these hormones play a crucial role in the function of the ovaries and testicles, reproductive performance is often associated with impairment [44,45]. The lower level of LH in summer is associated with lower estrogen secretion from the dominant ovarian

follicle, reduced sexual behavior, and decreased fertility [43]. Additionally, higher levels of ACTH and cortisol in heat-stressed animals can block estradiol-dependent sexual behavior [43]. A reduction in estrogen levels decreases ovulation rate in non-pregnant cows and lowers the birth weight of the calf in pregnant cattle [17]. Heat stress also reduces the occurrence and duration of estrus, changes the timing of estrus to nighttime, increases ovarian cysts, decreases blood flow to the uterus, decreases the pregnancy rate, increases the calving interval and placental retention in females and reduces testosterone concentration in males, decreasing sperm quality [17]. A reduction in birth weight and growth rate causes considerable losses to the livestock industry, and to prevent this as much as possible, the reproduction and breeding programs of animals should be managed in a way that is not associated with extreme environmental heat [2,15,46]. High ambient temperature significantly increases the temperature of the scrotal skin in males, decreases the level of testosterone, thereby causing sperm damage, lowers sperm production and motility, and decreases serum testosterone and libido [19].

Stress due to Water Deprivation and Dehydration

Lack of water in arid and semi-arid regions has always been a threat, and in recent years, due to problems related to global warming and changing rainfall patterns, this risk has become more critical [47]. In general, the effects of water stress on animals are similar to heat stress [48]. However, the observed effects are widely influenced by the type and intensity of water stress and its duration. Water is a significant factor in rumination, digestion, absorption, metabolism, and heat balance [49]. In

general, farm animals consume 2.87 liters of water per kilogram of feed [5], although this amount is 2 liters at temperatures between 9 and 20 °C [49] and with increasing temperatures up to 37 °C, it reaches more than 5 [33].

Water requirements are also affected by breed, production level, physiological condition, feed moisture, water quality, temperature, air humidity, heat, and solar radiation, among other factors [5,21,37,46]. Small ruminants, especially native animals of arid and semi-arid regions, possess a remarkable ability to thrive in environments with limited access to water and food compared to larger animals, such as dairy cows [50]. The production level of dairy animals is high; they need 4 to 5 kilograms of water per kilogram of milk produced. Desert sheep breeds have less water turnover and can withstand warmer environments better [21] by producing more concentrated urine and drier feces [47], nocturnal feeding [51], and lighter wool color [22]. Water stress creates a negative water balance in livestock so that the amount of water entering the body (through direct intake from the feed, water in the feed, and metabolic water created by the oxidation of carbohydrates, proteins, and fats) is less than the outgoing water (through urine, fecal moisture, and water lost by sweating and respiratory tracts [21]).

When sheep and goats acclimate to dehydration, they reduce thermoregulatory evaporative cooling mechanisms to conserve body water and prevent further dehydration [52]. Unlike camels, dehydrated sheep and goats preferentially turn to respiration to lose body heat instead of sweating [53]. This mechanism may be a way to achieve evaporative cooling of the brain region to minimize total water loss in dehydrated animals, which is probably achieved by heat transfer from arterial blood in the carotid to venous blood cooled by

respiratory evaporation in the nasal passages [54]. Brain cooling may also be responsible for the observed momentary hyperthermia often reported in dehydrated sheep, allowing temporary storage of heat during hot hours of the day followed by passive body cooling at night to minimize water loss [29, 47].

In nature, water limitation occurs in two ways: quantity and consumption time. Quantity restriction naturally reduces daily water intake [49,55], while time restriction can have different effects according to the duration of the deprivation [56,57]. Deprivation of 2 hours after each feeding in Holstein dairy cows [58] and one day in Santaines, fattening lambs does not affect water consumption [56], while deprivation of 2-3 hours after each feeding in Corridale sheep decreases water consumption by 15% [57]. Deprivations of 2-3 days reduce water consumption by 34 to 45% in fattening lambs [56] and 2-4 days in adult ewes reduce water consumption by 50 to 75% [59].

Feed and water consumption ratios are primarily related to each other and ambient temperature. When water restriction occurs during cold seasons and with small amounts, this ratio can be reduced due to no change in feed consumption [49,56]. However, 2-3 days of restrictions lead to a reduction in feed consumption by 20 and 30% in Santaines fattening lambs, respectively [56]. A five-day restriction in very young Awassi lambs causes a reduction of 28, 48, 79, 90 and 95% of feed in the first to fifth days of water restriction. Only after providing water, does feed consumption return to normal, and a large part of weight loss is compensated [60]. When Awassi sheep experienced a 4-day intermittent watering regime, free feed intake was reduced to 60% of controls [59], while a 2-3 hour post-feed restriction did not affect dry matter intake of high-producing Holstein dairy cows [58].

The severity of water restrictions directly affects the final weight and milk production. Restrictions of 2 hours after each meal increase 4% FCM by 12 percent in high-producing Holstein dairy cows because of increased digestibility [58], but limiting water consumption to 60 to 80% of daily consumption causes a three percent reduction in final weight in lactating sheep. Still, it did not affect milk production in them [49]. A one-day restriction in Santaines fattening lambs does not reduce dry matter intake or final weight at the end of the period. In contrast, two- to three-day restrictions cause weight loss by lowering feed consumption, and this reduction is more severe with three-day limits [56]. Generally, body weight loss is higher at the peak of lactation, in high ambient temperatures, and under severe water restrictions in young animals [21,61,62]. Part of the weight loss is due to water loss, while the other part is due to the mobilization of fat (and possibly muscle) to compensate for reduced energy intake from feed [59,61,62]. Additionally, a portion of this weight loss may be attributed to the rumen's emptying due to reduced feed intake, which occurs within several days. The rate of weight loss is faster in the early days, but after stabilizing, the rate of weight loss is due to the movement of fat, which occurs at a slower pace. Adding some additives, such as vitamin C, can reduce body weight loss in some studies where animals were subjected to water stress [63], although this effect was not observed in all studies [62].

Water restriction can increase blood concentration (hematocrit and hemoglobin). Fifty percent water restriction in young Balochi sheep [55] and eighty-five percent water restriction in non-lactating Awassi ewes [63] increases blood concentration, but rehydration after water restriction for five days in Awassi lambs, approached

hematocrit to the initial values [60]. Hematocrit and hemoglobin remained unchanged in 2- to 4-day water-restricted adult Awassi ewes [59], five days in very hot weather in Yankasa sheep [64], and 2-to 3-hour restriction after feed consumption in Corridal ewes [57]. The lack of increase in blood concentration in response to dehydration conditions in adult native animals in hot regions indicates their high ability to withstand harsh environments and adapt to those conditions. The amount of crude protein and albumin remained unchanged [55,57] or increased [47,59] in different studies. Albumin plays an essential role in assessing the level of dehydration and also plays a vital role in osmotic pressure, which guides the movement of fluids between different parts of the body [49,55,65].

As the body becomes dehydrated, the production of aldosterone and antidiuretic hormones increases, and urine production decreases [47,60]. Under these conditions, glomerular filtration decreases, and blood urea and creatinine levels increase. An increase in blood urea and creatinine levels was reported in Komisana sheep [49], Yankasa sheep [64], Awassi sheep [59], and Najdi [47] under water restrictions. There is reliable evidence that with long-term restrictions in water intake and consequent reductions in feed intake, blood urea levels begin to decrease, indicating an increase in urea entry into the rumen (urea recycling) [64,66]. An increase in aldosterone directly causes the release of potassium in the urine and its exchange with sodium and water [49]. However, in some studies, sodium and potassium levels increased under water deprivation due to dehydration and a lower plasma volume [55].

Water restriction, especially with reduced feed intake, mobilizes body fat stores. First, subcutaneous fat is mobilized, but when energy is not

prolonged, native breeds turn to their specialized fat reserves, such as fat-tail [67]. Similarly, other studies show increased free fatty acid levels in Awassi [62] and Sudanese desert sheep [68] under water deprivation, suggesting that fat is mobilized from adipocytes for fuel. Increased cholesterol levels are another indicator of fat mobilization in water-restricted sheep [59,62,64], which suggests a lack of energy in the diet. Blood insulin and leptin concentrations tended to decrease in water-restricted animals [62]. Low insulin levels facilitate lipolysis, which is necessary to compensate for dietary energy deficits [69]. Reduced thyroid hormone activity under dehydration is associated with the animal's attempt to minimize water loss by decreasing overall metabolism. T3 and T4 levels are reduced in some water-restricted studies [68,70], and this effect is reversed by rehydration [70].

Feed Scarcity and Malnutrition

Animals live in complex environments where they constantly face short-term and long-term unpleasant environmental factors such as temperature, photoperiod, geographic location, malnutrition, water deprivation, etc. [2]. Although climate change directly affects global warming, it also indirectly impacts pasture resources and food and water deprivation, making multiple stresses is a real threat in the arid and semi-arid areas [2,20]. Therefore, studying one factor alone does not yield accurate results if other factors are absent. However, there are limited studies on animals under thermal, nutritional, and walking stress, especially on Malpura sheep [14,15,37,46,71-75].

Table 1 Breed-specific physiological responses to water deprivation in sheep

Breed	Water Restriction Condition	Hematocrit / Hemoglobin	Feed Intake	Weight Change	Fat Mobilization Indicators	Ref.
Awassi (adult)	2-4 days, arid climate	No change	↓ up to 40%	↓ 3-5%	↑ FFA, ↑ Cholesterol, ↓ T3/T4	[59,62,64]
Awassi (lambs)	4-5 days intermittent	↑ (reversible)	↓ up to 95%	Severe ↓, recovered	↑ FFA, reversible after hydration	[60, 62]
Balochi (young)	50% water reduction	↑	↓ moderate	↓	↑ Urea, ↑ Creatinine	[55]
Santa Inês	1-3 day deprivation	No significant change	↓ after 2-3 days	↓ (3-day only)	Not reported	[56]
Yankasa	5 days, hot climate	No change	↓ moderate	↓ moderate	↑ Urea, ↑ Cholesterol	[64]
Najdi	80% restriction	↑ Urea, Creatinine	↓ moderate	↓ 4-6%	↑ Aldosterone, ↓ Insulin	[47]
Sudanese Desert	Not specified	Not specified	↓ moderate	↓ moderate	↑ FFA, ↑ Cholesterol	[68]
Corriedale	2-3 hr post-feed deprivation	No change	↓ ~15%	Slight ↓	Not reported	[57]
Holstein (control)	2 hr restriction after each feeding (dairy cow)	Not sheep, but ↑ FCM	No change	No loss	↑ Digestibility	[58]

When two stressors co-occur, the total impact can be severe on biological

functions [4,9]. Nutritional stress appears to be the most important type of

stress because other stressors like thermal stress and water stress indicate their effect by lowering DMI and subsequently affecting the production and reproduction of animals [2,19-21,47]. Quality and quantity fluctuations of feed resources are common in the arid and semi-arid areas [2,14,15], so they experience feed/multiple stressors.

RR and RT temperatures in Malpura ewes increased in response to thermal stress, especially in the afternoon. However, nutritional restriction decreased RT and RR due to the reduction of available substrates for enzymatic activities, the activity of rumen microbes, and the body's metabolic rate [37,38]. When nutritional stress is combined with heat stress or walking, or both, due to the need to excrete heat results in behavior similar to heat stress is seen, and the respiration rate and rectal temperature also increase. Still, this increase is less than heat stress alone, which indicates a decreased metabolic rate. A reduced heart rate also supports this idea, as there is a direct correlation between metabolic rate and heart rate [37,38].

Naturally, animals with limited access to feed (in quantity and quality) consume less dry matter and nutrients, which can cause weight loss. These seasonal changes occur naturally when there is a lack of natural food, called seasonal weight loss, and are usually observed in areas with seasonal changes in food abundance [76,77]. Most of the sheep in these areas have tails, which are traditionally considered one of the most influential factors in their ability to withstand harsh environments. The amount of weight loss was similar in 85% of the maintenance diet in Damara (fat-tailed) and Dropper and Australian Merino breeds (thin-tailed) in the 42 days was the same in the three breeds. However, the amount of daily weight gain of the breed in Damara breed was less favorable than the other

three breeds [78]. However, analysis of liver proteins showed that Damara uses adipose tissue stored in its fat tails to provide food in times of nutritional stress [76]. In these animals, fat reserves are converted into ATP through phosphorylation. This process is present but limited in humans and Merinos. In Damaras, this is downregulated, allowing them to easily utilize fat reserves in their tails easily. Merinos show a more significant number of proteins associated with muscle deposition and protein synthesis than with fat deposition. Also, in a study conducted on the pure Lori-Bakhtiari (fat-tailed) breed and its crossbred with Romanove, it was shown that a higher amount of fatty acid binding protein 4, which is responsible for the transfer of fatty acids in the cell, during the positive energy balance in the fat-tail of Lori-Bakhtiari [67].

In general, PCV and Hb are considered stress response indicators [2]. Hemoglobin (Hb) and hematocrit (PCV) are significantly reduced in the thermal, nutritional, and combined stress groups, but the difference in the multiple stress groups is more significant than in the individual stress groups [73]. In response to heat stress, the production of free radicals increases, which can cause a decrease in red blood cells and a reduction in PCV and Hb. Additionally, the entry of more water into the circulatory system for evaporative cooling results in a decrease in Hb and PCV in animals under heat stress [37]. The more significant decrease in hemoglobin and PCV in the double-stress groups could be attributed to a decrease in hemoglobin synthesis due to nutritional restriction, blood dilution, and destruction of red blood cells caused by heat stress. Plasma glucose can exhibit a different response to food restriction. Blood glucose in response to nutritional restriction under heat stress conditions in gestating Mexican hair ewes fed on

straw [79] and nutritional restriction alone in the Serrada Estrella breed [80] was stable over time, while it decreased in Malpura ewes with 60% free feed and multiple stresses [81]. The decrease in glucose levels during heat exposure is attributed to a reduction in DMI, followed by a decrease in insulin and thyroxine concentrations, which are closely related to energy metabolism during heat exposure. Decreased plasma glucose levels can also be due to blood dilution or increased utilization of glucose in the plasma to generate more energy for high muscle activity. Nutrient restriction, combined with increased glucose consumption resulting from increased respiratory muscle activity after heat exposure, reduces glucose concentration in the dual stress group [37,38,41]. The total plasma protein in individual stress groups, as well as in double and multiple stress groups, was significantly decreased compared to the control group [37,38]. Decreased plasma protein levels may be due to dilution of plasma proteins and reduced protein synthesis resulting from decreased anabolic hormone secretion. The biological significance of protein depletion in heat stress is the support of hepatic gluconeogenesis (by glucocorticoids) to increase glucose levels to cope with heat stress. During heat stress, the concentration of glucocorticoids increases [37,38]. One of the main functions of glucocorticoids is to support protein catabolism, which converts protein into amino acids, and to support gluconeogenesis. The association between heat stress and increased secretion of cortisol, the primary glucocorticoid hormone in small ruminants, is well documented [72,73,82]. The significant decrease in cortisol concentration in the double and multiple stress groups compared to the heat stress group indicates the difference in the adaptability of Malpura ewes in different situations. Cortisol is

thermogenic, and its function contributes to excess heat load. Thyroid hormone levels decrease during restriction, which is due to its role in heat production in the body [83]. Heat stress leads to a significant decrease in thyroid gland activity, resulting in lower thyroid hormone levels. Heat-nutrition stress and walking-heat-nutrition stress significantly lower thyroid hormone concentrations, much more than heat stress alone [37]. Cholesterol concentration also decreased significantly in the individual, double, and multiple stress groups. However, the reduction rate was higher in the multiple stress groups. This may be due to the increased use of fatty acids for energy production as a result of reduced glucose concentration in heat-stressed animals or limited cholesterol synthesis in multiple stress scenarios [2,41]. NEFA and total lipids increased in response to nutritional restriction, indicating the mobilization of these reserves to compensate for the body's energy requirements [80]. The endocrine stress response suppresses reproductive functions, such as growth and reproduction, but favors maintenance and survival [84]. In addition to delaying sexual maturity, undernutrition lowered the percentage of ewes in heat, estrus duration, and conception rate [85]. These adverse effects are mediated by suppression and enhancement in the concentration of estradiol and progesterone in ewes, respectively [85]. Glucocorticoids reduce the conversion of progesterone to estrogen in female ovarian follicles, which is caused by the suppressed peripheral concentration of gonadotropins [2].

The rate of progesterone secretion does not increase under stress, but the rate of its clearance decreases [2]. Glucocorticoids also increase aromatase activity in males, causing the conversion

of testosterone to estradiol. The possible reason for this could be the reduction of

the sex steroid receptors and the change in the concentration of sex steroids [84].

Table 2 Effect of feed scarcity and malnutrition on physiology, behavior, and production changes

Physiology	Behavior	Production	Remarks	Study Reference
High NEFA, low glucose	Lethargy, lameness	Weight loss	Reflects energy mobilization under stress	[48]
High cortisol, low thyroid	Panting, shade-seeking	Decreased ADG	Adaptive physiological response	[14]
Elevated urea, creatinine	Reduced movement	Decline in milk yield	Indicative of water and thermal stress	[59]
Reduced Hb, PCV	Decreased activity	Lower fertility rate	Due to combined heat and nutrition stress	[72]
Stable glucose, high cholesterol	Normal grazing	Maintained weight	Resilience in native lambs under water restriction	[47]

Stress Due to Extreme Cold and Breeze

Exposure to cold temperatures, particularly when coupled with wind chill, poses a significant risk to small ruminants. Cold stress typically increases maintenance energy requirements as animals expend more energy to maintain core body temperature. Neonatal lambs and kids are especially vulnerable. Cold temperatures impair immune function, delay growth, and increase mortality. Windbreaks, adequate shelter, and dietary energy supplementation are effective countermeasures against these conditions.

Stress Due to External Parasites and Subclinical Diseases

Ectoparasites, such as ticks and lice, cause chronic stress through irritation and blood loss, and can transmit diseases. Subclinical infections further impair immunity and feed efficiency. Regular deworming, pasture rotation, and ectoparasite control programs are essential for maintaining animal performance.

Conclusion

Understanding how multiple environmental stressors interact is

crucial for developing comprehensive mitigation strategies. Future research should focus on breed-specific resilience, early biomarkers of stress, nutritional supplementation, and innovative management techniques. Integrating traditional knowledge with modern technologies and policy support is vital for the development of effective mitigation strategies. Climate change has led to a significant increase in the quantity and quality of stress on farm animals, particularly in arid and semi-arid regions. Temperature increases, reductions in precipitation, and water restrictions, as well as feed scarcity and limitations, are stressful factors; in general, these factors often occur in combination in nature. The review reveals that when these factors combine and persist for a prolonged period, their impact on animals is greater, making it more difficult for them to recover. When the body receives a threat to homeostasis, and first tries to overcome it with a behavioral response that does not work, it develops autonomic, neuroendocrine, and immunological responses which may cause alterations in biological functions such as catabolism of body reserves. Finally, further prolongation of stress factors may lead to a prepathological/pathological state

causing illness or death. The review indicates all these stressful conditions mediate through physiological changes (RT, RR, etc.), production performance (DMI, WI, ADG, FW, milk yield, etc.), reproduction (open days, birth weight, etc.), and blood basal metabolism (glucose, urea, albumin, hormones, etc.) parameters, which could decrease ultimate productivity of farm animals, leading to low profit margin for farmers. All these environmental stressors, ultimately affect the quality and quantity of feed and animal consumption. Therefore, managing the destructive factors affecting these animals to reduce their effects, especially by enriching and offering feed, can improve animal production and reproduction, ensuring animal profitability during periods of unfavorable conditions.

Authors' Contribution

Kobra Pourasad-Astamal: Data collection, data interpretation, Study design, and initial draft preparation. Nemat Hedayat: Conceptualization, study design, data interpretation, and critical revision of the manuscript. Vahid Vahedi: Methodology support, validation, manuscript editing. Reza Seyedsharifi: Methodology support, Validation, and review of the manuscript. Hussein Tanveer: Literature review, and language editing.

ORCID

Kobra Pourasad-Astamal

<https://orcid.org/0009-0002-5690-3113>

Nemat Hedayat

<https://orcid.org/0000-0002-6802-6739>

Vahid Vahedi

<https://orcid.org/0000-0001-5678-6995>

Reza Seyedsharifi

<https://orcid.org/0000-0003-4593-2058>

Hussein Tanveer

<https://orcid.org/0000-0002-2522-2406>

References

- [1]. Endris, M., Feki, E., [Review on effect of stress on animal productivity and response of animal to stressors](#). *Journal of Animal and Veterinary Advances*, **2021**, 20(1), 1-14.
- [2]. Sejian, V., Maurya, V.P., Sharma, K.C., Naqvi, S., [Concept of multiple stresses and its significance on livestock productivity](#). *Environmental Stress and Amelioration in Livestock Production*, **2012**, 129-150.
- [3]. Ashour, G., Benlemlih, S., [Adaptation of mediterranean breeds to heat stress and water deprivation](#). *Livestock Production and Climatic Uncertainty in the Mediterranean*, **2000**, 63-74.
- [4]. Sejian, V., Bhatta, R., Gaughan, J., Dunshea, F., Lacetera, N., [Adaptation of animals to heat stress](#). *Animal*, **2018**, 12(s2), s431-s444.
- [5]. Ruminants, N.R.C.C.o.N.R.o.S. [Nutrient requirements of small ruminants: Sheep, goats, cervids, and new world camelids](#). **2007**.
- [6]. Tansman, G.F., Kindstedt, P.S., Hughes, J.M., [Crystallization and demineralization phenomena in washed-rind cheese](#). *Journal of Dairy Science*, **2017**, 100(11), 8694-8704.
- [7]. Moberg, G.P., [Biological response to stress: Key to assessment of animal well-being?](#) *Animal Stress*, **1985**, 27-49.
- [8]. Ziegler, M.G., [Psychological stress and the autonomic nervous system](#). *Primer on the Autonomic Nervous System*, **2012**, 291-293.
- [9]. Moberg, G.P., [Biological response to stress: Implications for animal welfare](#). *The Biology of Animal Stress: Basic Principles and Implications for Animal Welfare.*, **2000**, 1-21.
- [10]. Cockrem, J.F., [Individual variation in glucocorticoid stress responses in animals](#). *General and Comparative Endocrinology*, **2013**, 181, 45-58.
- [11]. Elsasser, T., Klasing, K., Filipov, N., Thompson, F., [The metabolic consequences of stress: Targets for stress and priorities of nutrient use](#). **2000**.

- [12]. Starkie, R., Hargreaves, M., Rolland, J., Febbraio, M.A., [Heat stress, cytokines, and the immune response to exercise](#). *Brain, Behavior, and Immunity*, **2005**, 19(5), 404-412.
- [13]. Nieto-Vazquez, I., Fernández-Veledo, S., Krämer, D.K., Vila-Bedmar, R., Garcia-Guerra, L., Lorenzo, M., [Insulin resistance associated to obesity: The link tnf-alpha](#). *Archives of Physiology and Biochemistry*, **2008**, 114(3), 183-194.
- [14]. Veerasamy Sejian, V.S., Davendra Kumar, D.K., Gaughan, J., Naqvi, S., [Effect of multiple environmental stressors on the adaptive capability of malpura rams based on physiological responses in a semi-arid tropical environment](#). **2017**.
- [15]. Sejian, V., Maurya, V., Kumar, K., Naqvi, S., [Effect of multiple stresses \(thermal, nutritional, and walking stress\) on the reproductive performance of malpura ewes](#). *Veterinary Medicine International*, **2012**, 2012(1), 471760.
- [16]. Abrar Ahmed, A.A., Tiwari, R., Mishra, G., Biswadeep Jena, B.J., Dar, M.A., Bhat, A.A., [Effect of environmental heat stress on reproduction performance of dairy cows-a review](#). **2015**.
- [17]. Atrian, P., Shahryar, H.A., [Heat stress in dairy cows \(a review\)](#). **2012**.
- [18]. Ghassemi Nejad, J., Kim, B.W., Lee, B.H., Sung, K.I., [Coat and hair color: Hair cortisol and serotonin levels in lactating holstein cows under heat stress conditions](#). *Animal Science Journal*, **2017**, 88(1), 190-194.
- [19]. Marai, I., El-Darawany, A., Fadiel, A., Abdel-Hafez, M., [Physiological traits as affected by heat stress in sheep—a review](#). *Small Ruminant Research*, **2007**, 71(1-3), 1-12.
- [20]. Lees, A.M., Sejian, V., Wallage, A.L., Steel, C.C., Mader, T.L., Lees, J.C., Gaughan, J.B., [The impact of heat load on cattle](#). *Animals*, **2019**, 9(6), 322.
- [21]. Chedid, M., Jaber, L.S., Giger-Reverdin, S., Duvaux-Ponter, C., Hamadeh, S.K., [Water stress in sheep raised under arid conditions](#). *Canadian Journal of Animal Science*, **2014**, 94(2), 243-257.
- [22]. McManus, C., Paludo, G.R., Louvandini, H., Gugel, R., Sasaki, L.C.B., Paiva, S.R., [Heat tolerance in Brazilian sheep: Physiological and blood parameters](#). *Tropical Animal Health and Production*, **2009**, 41(1), 95-101.
- [23]. Bagath, M., Krishnan, G., Devaraj, C., Rashamol, V., Pragna, P., Lees, A., Sejian, V., [The impact of heat stress on the immune system in dairy cattle: A review](#). *Research in Veterinary Science*, **2019**, 126, 94-102.
- [24]. West, J.W., [Effects of heat-stress on production in dairy cattle](#). *Journal of Dairy Science*, **2003**, 86(6), 2131-2144.
- [25]. Silanikove, N., [Effects of heat stress on the welfare of extensively managed domestic ruminants](#). *Livestock Production Science*, **2000**, 67(1-2), 1-18.
- [26]. Sevi, A., Annicchiarico, G., Albenzio, M., Taibi, L., Muscio, A., Dell'Aquila, S., [Effects of solar radiation and feeding time on behavior, immune response and production of lactating ewes under high ambient temperature](#). *Journal of Dairy Science*, **2001**, 84(3), 629-640.
- [27]. Renaudeau, D., Collin, A., Yahav, S., De Basilio, V., Gourdine, J.L., Collier, R., [Adaptation to hot climate and strategies to alleviate heat stress in livestock production](#). *Animal*, **2012**, 6(5), 707-728.
- [28]. Alamer, M., Al-hozab, A., [Effect of water deprivation and season on feed intake, body weight and thermoregulation in awassi and najdi sheep breeds in Saudi Arabia](#). *Journal of Arid Environments*, **2004**, 59(1), 71-84.
- [29]. Brown-Brandl, T., Nienaber, J., Eigenberg, R., Hahn, G., Freetly, H., [Thermoregulatory responses of feeder cattle](#). *Journal of Thermal Biology*, **2003**, 28(2), 149-157.
- [30]. Min, L., Cheng, J., Shi, B., Yang, H., Zheng, N., Wang, J., [Effects of heat stress on serum insulin, adipokines, amp-activated protein kinase, and heat shock signal molecules in](#)

dairy cows. *Journal of Zhejiang University-Science B*, **2015**, 16(6), 541-548.

[31]. Beede, D., Collier, R., Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of Animal Science*, **1986**, 62(2), 543-554.

[32]. Alhidary, I., Shini, S., Al Jassim, R., Gaughan, J., Physiological responses of australian merino wethers exposed to high heat load. *Journal of Animal Science*, **2012**, 90(1), 212-220.

[33]. Wankar, A.K., Rindhe, S.N., Doijad, N.S., Heat stress in dairy animals and current milk production trends, economics, and future perspectives: The global scenario. *Tropical Animal Health and Production*, **2021**, 53(1), 70.

[34]. Bohmanova, J., Misztal, I., Cole, J.B., Temperature-humidity indices as indicators of milk production losses due to heat stress. *Journal of Dairy Science*, **2007**, 90(4), 1947-1956.

[35]. Aggarwal, A., Upadhyay, R. Heat stress and hormones. *Heat Stress and Animal Productivity*, **2012**, 27-51.

[36]. Bohmanova, J., Misztal, I., Cole, J.B., Temperature-humidity indices as indicators of milk production losses due to heat stress. *Journal of Dairy Science*, **2007**, 90(4), 1947-1956.

[37]. Sejian, V., Maurya, V.P., Naqvi, S.M., Adaptability and growth of malpura ewes subjected to thermal and nutritional stress. *Tropical Animal Health and Production*, **2010**, 42(8), 1763-1770.

[38]. Sejian, V., Maurya, V.P., Naqvi, S.M., Adaptive capability as indicated by endocrine and biochemical responses of malpura ewes subjected to combined stresses (thermal and nutritional) in a semi-arid tropical environment. *International Journal of Biometeorology*, **2010**, 54(6), 653-661.

[39]. Nejad, J.G., Lohakare, J., Son, J., Kwon, E., West, J., Sung, K., Wool cortisol is a better

indicator of stress than blood cortisol in ewes exposed to heat stress and water restriction. *Animal*, **2014**, 8(1), 128-132.

[40]. Habeeb AA. Symptoms of heat stress in tropical and subtropical regions on farm animals. *European Journal of Agriculture and Food Sciences*, **2020**, 2(6).

[41]. Rasouli, A., Nouri, M., Khajeh, G.H., Rasekh, A., The influences of seasonal variations on thyroid activity and some biochemical parameters of cattle. **2004**.

[42]. Al-Haidary, A.A., Physiological responses of naimey sheep to heat stress challenge under semi-arid environments. *International Journal of Agriculture and Biology*, **2004**, 2(6), 307-309.

[43]. Sammad, A., Wang, Y.J., Umer, S., Lirong, H., Khan, I., Khan, A., Ahmad, B., Wang, Y., Nutritional physiology and biochemistry of dairy cattle under the influence of heat stress: Consequences and opportunities. *Animals*, **2020**, 10(5), 793.

[44]. Martin, G., Rodger, J., Blache, D., Nutritional and environmental effects on reproduction in small ruminants. *Reproduction, Fertility and Development*, **2004**, 16(4), 491-501.

[45]. Breen, K.M., Karsch, F.J., New insights regarding glucocorticoids, stress and gonadotropin suppression. *Frontiers in Neuroendocrinology*, **2006**, 27(2), 233-245.

[46]. Sejian, V., Maurya, V.P., Kumar, K., Naqvi, S.M.K., Effect of multiple stresses on growth and adaptive capability of malpura ewes under semi-arid tropical environment. *Tropical Animal Health and Production*, **2012**, 45(1), 107-116.

[47]. Adeniji, Y.A., Sanni, M.O., Abdoun, K.A., Samara, E.M., Al-Badwi, M.A., Bahadi, M.A., Alhidary, I.A., Al-Haidary, A.A., Resilience of lambs to limited water availability without compromising their production performance. *Animals*, **2020**, 10(9), 1491.

[48]. Jaber, L.S., Duvaux-Ponter, C., Hamadeh, S.K., Giger-Reverdin, S., Mild heat stress and short water restriction treatment in lactating

- alpine and saanen goats. *Small Ruminant Research*, **2019**, 175, 46-51.
- [49]. Casamassima, D., Pizzo, R., Palazzo, M., D'alessandro, A., Martemucci, G., **Effect of water restriction on productive performance and blood parameters in comisana sheep reared under intensive condition.** *Small Ruminant Research*, **2008**, 78(1-3), 169-175.
- [50]. Akinmoladun, O.F., Muchenje, V., Fon, F.N., Mpendulo, C.T., **Small ruminants: Farmers' hope in a world threatened by water scarcity.** *Animals*, **2019**, 9(7), 456.
- [51]. Dwyer, C.M., **Environment and the sheep: Breed adaptations and welfare implications.** *The Welfare of sheep*, **2008**, 41-79.
- [52]. McKinley, M.J., Weissenborn, F., Mathai, M.L., **Drinking-induced thermoregulatory panting in rehydrated sheep: Influences of oropharyngeal/esophageal signals, core temperature, and thirst satiety.** *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, **2009**, 296(6), R1881-R1888.
- [53]. Robertshaw, D., **Mechanisms for the control of respiratory evaporative heat loss in panting animals.** *Journal of Applied Physiology*, **2006**, 101(2), 664-668.
- [54]. Fuller, A., Meyer, L.C., Mitchell, D., Maloney, S.K., **Dehydration increases the magnitude of selective brain cooling independently of core temperature in sheep.** *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, **2007**, 293(1), R438-R446.
- [55]. Vosooghi-Postindoz, V., Tahmasbi, A., Naserian, A.A., Valizade, R., Ebrahimi, H., **Effect of water deprivation and drinking saline water on performance, blood metabolites, nutrient digestibility, and rumen parameters in baluchi lambs.** *Iranian Journal of Applied Animal Science*, **2018**, 8(3).
- [56]. Dos Santos, F.M., de Araújo, G.G.L., de Souza, L.L., Yamamoto, S.M., Queiroz, M.A.Á., Lanna, D.P.D., de Moraes, S.A., **Impact of water restriction periods on carcass traits and meat quality of feedlot lambs in the brazilian semi-arid region.** *Meat science*, **2019**, 156, 196-204.
- [57]. Nejad, J.G., Lohakare, J., West, J., Sung, K., **Effects of water restriction after feeding during heat stress on nutrient digestibility, nitrogen balance, blood profile and characteristics in corriedale ewes.** *Animal Feed Science and Technology*, **2014**, 193, 1-8.
- [58]. Nejad, J.G., Lohakare, J.D., West, J.W., Kim, B.W., Lee, B.H., Sung, K.I., **Effects of water restriction following feeding on nutrient digestibilities, milk yield and composition and blood hormones in lactating holstein cows under heat stress conditions.** *Italian Journal of Animal Science*, **2015**, 14(3), 3952.
- [59]. Jaber, L., Habre, A., Rawda, N., Abi Said, M., Barbour, E., Hamadeh, S., **The effect of water restriction on certain physiological parameters in awassi sheep.** *Small ruminant Research*, **2004**, 54(1-2), 115-120.
- [60]. Laden, S., Nehmadi, L., Yagil, R., **Dehydration tolerance in awassi fat-tailed sheep.** *Canadian Journal of Zoology*, **1987**, 65(2), 363-367.
- [61]. Hamadeh, S., Rawda, N., Jaber, L., Habre, A., Abi Said, M., Barbour, E., **Physiological responses to water restriction in dry and lactating awassi ewes.** *Livestock Science*, **2006**, 101(1-3), 101-109.
- [62]. Jaber, L., Hanna, N., Barbour, E., Abi Said, M., Rawda, N., Chedid, M., Hamadeh, S., **Fat mobilization in water restricted awassi ewes supplemented with vitamin c.** *Journal of Arid Environments*, **2011**, 75(7), 625-628.
- [63]. Ghanem, A., Jaber, L., Abi Said, M., Barbour, E., Hamadeh, S., **Physiological and chemical responses in water-deprived awassi ewes treated with vitamin c.** *Journal of Arid Environments*, **2008**, 72(3), 141-149.
- [64]. Igbokwe, I., **Haemoconcentration in yankasa sheep exposed to prolonged water deprivation.** *Small Ruminant Research*, **1993**, 12(1), 99-105.

- [65]. Burton, R., [The protein content of extracellular fluids and its relevance to the study of ionic regulation: Net charge and colloid osmotic pressure.](#) *Comparative Biochemistry and Physiology. A, Comparative Physiology*, **1988**, 90(1), 11-16.
- [66]. Marini, J., Klein, J., Sands, J., Van Amburgh, M., [Effect of nitrogen intake on nitrogen recycling and urea transporter abundance in lambs.](#) *Journal of Animal Science*, **2004**, 82(4), 1157-1164.
- [67]. Bahnamiri, H.Z., Zali, A., Ganjkhanlou, M., Sadeghi, M., Shahrabak, H.M., [Regulation of lipid metabolism in adipose depots of fat-tailed and thin-tailed lambs during negative and positive energy balances.](#) *Gene*, **2018**, 641, 203-211.
- [68]. Abdelatif, A., Ahmed, M.M., [Water restriction, thermoregulation, blood constituents and endocrine responses in sudanese desert sheep.](#) *Journal of Arid Environments*, **1994**, 26(2), 171-180.
- [69]. Chilliard, Y., Ferlay, A., Faulconnier, Y., Bonnet, M., Rouel, J., Bocquier, F., [Adipose tissue metabolism and its role in adaptations to undernutrition in ruminants.](#) *Proceedings of the Nutrition Society*, **2000**, 59(1), 127-134.
- [70]. Nalini Kataria, N.K., Kataria, A., [Endocrine and metabolic responses of marwari sheep in arid tract.](#) **2006**.
- [71]. Chaidanya, K., Soren, N.M., Sejian, V., Bagath, M., Manjunathareddy, G.B., Kurien, E.K., Varma, G., Bhatta, R., [Impact of heat stress, nutritional stress and combined \(heat and nutritional\) stresses on rumen associated fermentation characteristics, histopathology and hsp70 gene expression in goats.](#) *Journal of Animal Behaviour and Biometeorology*, **2017**, 5(2), 36-48.
- [72]. Maurya, V., Sejian, V., Kumar, D., Naqvi, S., [Impact of heat stress, nutritional restriction and combined stresses \(heat and nutritional\) on growth and reproductive performance of malpura rams under semi-arid tropical environment.](#) *Journal of Animal Physiology and Animal Nutrition*, **2016**, 100(5), 938-946.
- [73]. Maurya, V.P., Sejian, V., Kumar, D., Naqvi, S.M.K., [Impact of heat stress, nutritional stress and their combinations on the adaptive capability of malpura sheep under hot semi-arid tropical environment.](#) *Journal of Animal Behaviour and Biometeorology*, **2020**, 7(1), 17-23.
- [74]. Sejian, V., Bahadur, S., Naqvi, S.M., [Effect of nutritional restriction on growth, adaptation physiology and estrous responses in malpura ewes.](#) *Animal Biology*, **2014**, 64(2), 189-205.
- [75]. Shaji, S., Sejian, V., Bagath, M., Manjunathareddy, G., Kurien, E., Varma, G., Bhatta, R., [Summer season related heat and nutritional stresses on the adaptive capability of goats based on blood biochemical response and hepatic hsp70 gene expression.](#) *Biological Rhythm Research*, **2017**, 48(1), 65-83.
- [76]. Miller, B., Selevsek, N., Grossmann, J., Kilminster, T., Scanlon, T., Daniels, M., Nanni, P., Milton, J., Oldham, C., Greeff, J., [Ovine liver proteome: Assessing mechanisms of seasonal weight loss tolerance between merino and damara sheep.](#) *Journal of Proteomics*, **2019**, 191, 180-190.
- [77]. Zhang, T.T., Zhang, G.M., Jin, Y.H., Guo, Y.X., Wang, Z., Fan, Y.X., El-Samahy, M., Wang, F., [Energy restriction affect liver development in hu sheep ram lambs through hippo signaling pathway.](#) *Tissue and Cell*, **2017**, 49(5), 603-611.
- [78]. Scanlon, T., Almeida, A.M., Van Burgel, A., Kilminster, T., Milton, J., Greeff, J.C., Oldham, C., [Live weight parameters in dorper, damara and australian merino lambs subjected to restricted feeding.](#) *Small Ruminant Research*, **2013**, 109(2-3), 101.
- [79]. Macías-Cruz, U., Álvarez-Valenzuela, F., Correa-Calderón, A., Díaz-Molina, R., Mellado, M., Meza-Herrera, C., Avendaño-Reyes, L., [Thermoregulation of nutrient-restricted hair ewes subjected to heat stress during late](#)

pregnancy. *Journal of Thermal Biology*, **2013**, 38(1), 1-9.

[80]. Caldeira, R., Belo, A., Santos, C., Vazques, M., Portugal, A., **The effect of long-term feed restriction and over-nutrition on body condition score, blood metabolites and hormonal profiles in ewes.** *Small Ruminant Research*, **2007**, 68(3), 242-255.

[81]. Sejian, V., Bagath, M., Parthipan, S., Manjunathareddy, G.B., Selvaraju, S., Archana, S.S., Soren, N.M., Rao, S.B.N., Giridhar, K., Ravindra, J.P., **Effect of different diet level on the physiological adaptability, biochemical and endocrine responses and relative hepatic hsp70 and hsp90 genes expression in osmanabadi kids.** *Journal of Agricultural Science and Technology A*, **2015**, 5, 755-769.

[82]. Sejian, V., Srivastava, R., Varshney, V., **Pineal-adrenal relationship: Modulating effects of glucocorticoids on pineal function to ameliorate thermal-stress in goats.** *Asian-*

Australasian Journal of Animal Sciences, **2008**, 21(7), 988-994.

[83]. Krassas, G.E., Pontikides, N., **Male reproductive function in relation with thyroid alterations.** *Best Practice & Research Clinical Endocrinology & Metabolism*, **2004**, 18(2), 183-195.

[84]. Lundgren, M., Burén, J., Ruge, T., Myrnas, T., Eriksson, J.W., **Glucocorticoids down-regulate glucose uptake capacity and insulin-signaling proteins in omental but not subcutaneous human adipocytes.** *The Journal of Clinical Endocrinology & Metabolism*, **2004**, 89(6), 2989-2997.

[85]. Sejian, V., Maurya, V., Naqvi, S., **Effect of thermal stress, restricted feeding and combined stresses (thermal stress and restricted feeding) on growth and plasma reproductive hormone levels of malpura ewes under semi-arid tropical environment.** *Journal of Animal Physiology and Animal Nutrition*, **2011**, 95(2), 252-258.

How to cite this article:

K. Pourasad-Astamal, N. Hedayat, V. Vahedi, R. Seyedsharifi, H. Tanveer, Environmental Stressors and Productivity of Small Ruminants in Arid and Semi-Arid Regions: Physiological, Behavioral, and Health Responses. *International Journal of Advanced Biological and Biomedical Research*, 2026, 14(1), 29-47.

DOI: <https://doi.org/10.48309/ijabbr.2026.2066432.1640>

Link: https://www.ijabbr.com/article_729136.html