Climate change impacts on sheep and goat production and reproduction

Anass BEN MOULA[1] (✉), Amr KCHIKICH[2], Mouad CHENTOUF[3], Ahlem HAMDACHE[1], Khalid BOURAADA[1], Mariam ESSAFI[4], Mohammed EZZIYYANI[1]

[1] Plant, Microbial, Marine, and Precision Agriculture Biotechnology research team; Laboratory of Natural and Economic Resources for Sustainable Development, Department of Life Sciences, Polydisciplinary Faculty of Larache (FPL), Abdelmalek Essaadi University, 745 BP, 92004 Larache, Morocco

[2] Laboratory of Biotechnological Valorization of Microorganisms, Genomics, and Bioinformatics, Faculty of Sciences and Techniques, University Abdelmalek Essaadi, Tangier, Morocco

[3] Animal Production Unit, Regional Centre for Agricultural Research of Tangier, National Institute for Agricultural Research (INRA), Avenue Ennasr, P.O. Box 415 Rabat Principal, 10090 Rabat, Morocco

[4] Regional Public Health Laboratory (L.R.S.P.), Ministry of Health and Social Protection, Regional Directorate of Health and Social Protection Fez-Meknes, Morocco

✉ Corresponding author: a.benmoula@uae.ac.ma

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ABSTRACT

In regions facing extreme heat, livestock encounter formidable challenges in dissipating environmental heat, leading to recurrent and severe heat stress episodes throughout the year. This review delves into the physiological impacts of climate change on sheep and goat production, with a focus on economic viability, milk and meat yields, reproductive performance, and thermoregulation. In arid and semi-arid regions, sheep and goats are particularly vulnerable to elevated temperatures, experiencing reductions in body weight, average daily gain, growth rates, and reproductive impairments. Besides, the combination of heat and humidity further undermines animals' immune systems, rendering them more susceptible to diseases and stress. However, goats demonstrate resilience and adaptive advantages over sheep in mitigating heat stress effects, rooted in their unique physiological, morphological, and behavioral adaptations. Leveraging these adaptive traits offers opportunities for sustainable livestock farming within intensifying climatic challenges, emphasizing the necessity of proactive management strategies to safeguard livestock welfare and promote economic viability.

Keywords: climate change, small ruminants' production, reproduction, heat stress, sheep, goats

INTRODUCTION

The increase in greenhouse gases, primarily due to factors such as industrialization, energy production, population growth, urbanization, and agriculture, is the main driver of climate change (Stern and Kaufmann, 2014). Besides, in regions grappling with extreme climatic conditions, livestock encounter significant hurdles in dissipating environmental heat, resulting in recurrent and severe heat stress episodes throughout the year (Srivastava et al., 2021).

Agricultural production is highly dependent on climate, which has been undergoing constant change recently. Scientific evidence indicates that climate change increasingly impacts life on the planet, posing a significant threat to sustainable development and the future of humankind (Choudhary and Gupta, 2024). This impact extends to animal production, especially in regions crucial for human diet and livelihoods (Malhi et al., 2020). Climate change amplifies the vulnerability of livestock systems, with phenomena like drought exacerbating emerging stresses. Additionally, climate change poses significant challenges to natural resources essential for animal production (Daramola et al., 2012; Bogale and Erena, 2022). This challenge compromises the animals' physiological equilibrium, leading to compromised conditions and diminished performance compared to counterparts in more temperate environments (Mezősi, 2022; Ben Moula et al., 2024). The complex physiological responses to heat stress, including sweating, elevated respiratory rates, and increased blood flow, constitute an adaptive strategy aimed at reducing metabolic rates, curtailing dry matter intake, and orchestrating alterations in water metabolism (McManus et al., 2022). While these adaptive mechanisms are vital for heat dissipation, they affect livestock production performance, impacting metrics such as daily weight gain and feed conversion efficiency (Daramola et al., 2012; Liu et al., 2017). Further complicating matters, the combination of heat and humidity undermines animals' immune systems, rendering them more susceptible to diseases and stress (Al-Dawood, 2017).

Sheep and goats, among various livestock species, are notably susceptible to high temperatures, which adversely affect their production and reproduction efficiency (McManus et al., 2020; Gupta and Mondal, 2021; Ben Moula et al., 2024).

This review provides an exploration of the intricate physiological implications of heat stress on sheep and goat production and reproductive traits.

IMPACT OF CLIMATE CHANGE ON THE ECONOMIC VIABILITY OF SHEEP AND GOAT PRODUCTION

Global climate change is anticipated to have profound effects on various environmental factors such as temperature, precipitation, atmospheric CO_2 levels, and water availability. These changes are poised to impact both crop and livestock systems significantly (Mezősi, 2022). In the context of livestock, alterations in the thermal environment due to climate change could affect animal health, reproduction, and feed efficiency, thereby impacting production costs and profitability (Figure 1). Increased thermal stress may result in reduced animal production and profitability by lowering feed efficiency, milk production, and reproduction rates (Aich, 2018; Xu et al., 2019; Abdallah et al., 2024).

The livelihoods of individuals in developing countries, particularly shepherds and farmers, are heavily reliant on local natural resource-based activities such as crop and livestock production (Rust and Rust, 2013). Negative weather impacts on livestock rearing pose a threat to their livelihoods, as their income is closely tied to the performance of these animals. Factors like lack of balanced nutrition, improper housing systems, inadequate livestock health care, and poor management practices further contribute to livelihood insecurities in these communities (Rust and Rust, 2013; Zurak et al., 2023).

Regarding feed and water intakes in sheep and goats, climate change triggers significant physiological, metabolic, and behavioral adaptations in response to changing environmental conditions. Heat stress disrupts rumen fermentation and reduces feed intake in sheep (DiGiacomo et al., 2021), while increasing water intake as they attempt to regulate body temperature (Marai et al., 2007) (Table 1). Goats, however, exhibit resilience to climatic variations due to unique physiological and behavioral traits. Their ability to browse a wide range of plant species and adjust feeding patterns helps mitigate the adverse effects of heat stress (Sejian et al., 2021b).

Indirect consequences of climate change, such as changes in vegetation composition and distribution, also affect feed and water availability for small ruminants.

Desertification processes driven by global warming led to the degradation of natural pasturelands, reducing suitable forage for grazing animals. Adaptive strategies are necessary to ensure adequate nutrition and water provision for sheep and goats throughout the year amidst these environmental changes.

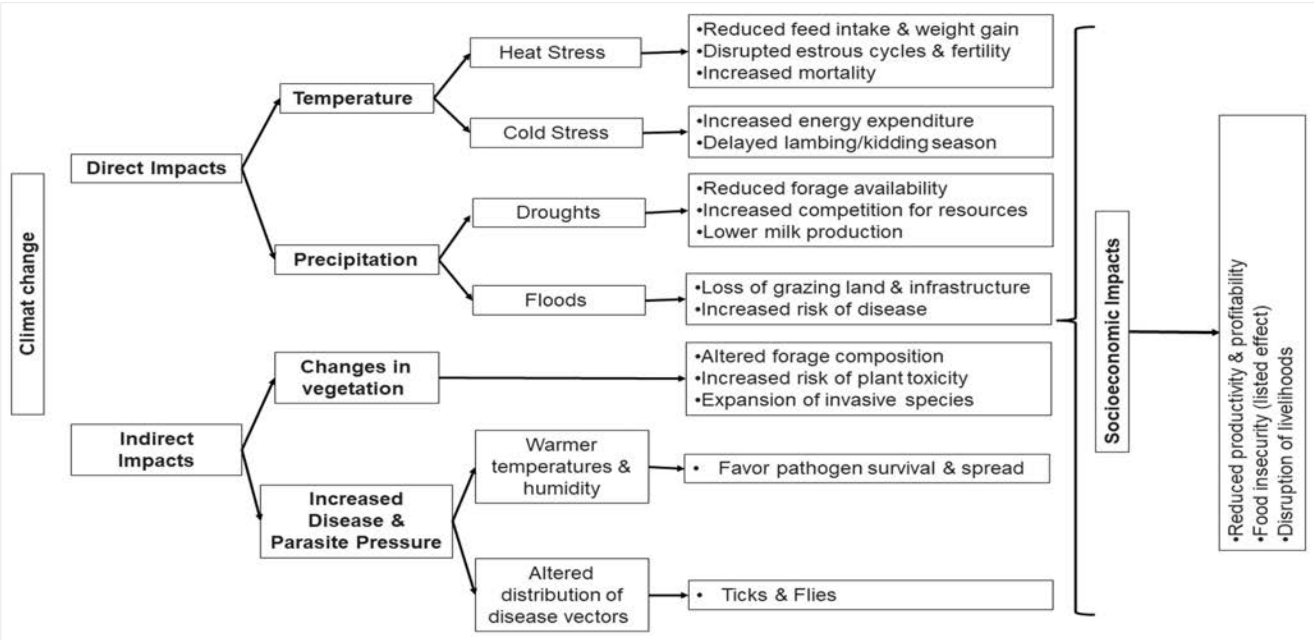

Figure 1. The cascading effects of climate change on sheep and goat herds

EFFECT OF CLIMATE CHANGE ON MILK AND MEAT PRODUCTIONS IN SHEEP AND GOAT

Climate change has significant implications for milk and meat production in sheep and goats, with alterations in temperature and humidity directly impacting productivity and product quality (Marino et al., 2016) (Table 1). Studies have shown that elevated temperatures detrimentally affect milk yield in various sheep breeds. For instance, in Comisana sheep, milk production declines by 20% when temperatures exceed 35 °C, while Sarda sheep experience a 30% decrease in milk yield when maximum and mean temperatures surpass 21 to 24 °C and 15 to 21 °C, respectively. Moreover, exposure to high temperatures leads to immediate reductions in milk production, fat, and protein yields in Manchega sheep, further exacerbating the challenges posed by climate change (Ramón et al., 2016; Bendelja Ljoljić et al., 2018; Mehaba et al., 2021). Additionally, environmental stressors influence the composition of milk, with Comisana ewes exhibiting altered fatty acid profiles under solar radiation exposure, impacting milk quality (Sevi et al., 2002).

In the context of meat production, climate change-induced heat stress adversely affects carcass traits, meat quality, and health safety in sheep. Increased ambient temperatures, accompanied by humidity and solar radiation, elevated body temperatures, leading to physiological changes that affect meat color, pH levels, and tenderness. For example, Barbados Black Belly lambs subjected to different temperature conditions exhibit variations in meat color and pH, highlighting the impact of heat stress on meat characteristics (Ruiz-Ortega et al., 2022). Furthermore, heat stress-induced dehydration and metabolic changes result in tougher meat and reduced carcass yield, exacerbating the challenges faced by the sheep industry (Gregory, 2010).

In contrast to sheep, goats demonstrate greater resilience to climate change-induced heat stress, with minimal reductions in milk yield observed under high-temperature conditions (Rolinec et al., 2018; Sejian et al., 2021a). Studies indicate that dairy goats, particularly those adapted to hot environments, exhibit less sensitivity to heat stress compared to dairy cows, maintaining milk production with minimal decline (Koluman Darcan and Silanikove, 2018). Additionally, indigenous goat breeds in Mediterranean and subtropical regions display adaptive responses to heat stress, maintaining milk yield by losing body mass and exhibiting physiological changes conducive to survival in challenging climatic conditions (Sejian et al., 2019).

Table 1. Impact of heat stress on goat and sheep health, reproduction, and milk and meat production

	Goat response	Sheep response	References
Health	**Reduced:** reduced body weight and condition, thyroid stimulating hormone and plasma triiodothyronine, total leukocyte count, blood serum glucose and total protein levels, urination and defecation frequency, visceral blood flow, and food intake	**Reduced:** circulating glucose, cholesterol levels, growth rate, feed and water intakes	El-Tarabany et al., 2017 Rathwa et al., 2017 Archana et al., 2018 Pragna et al., 2018 Belhadj Slimen et al., 2019 Kitajima et al., 2021
	Increased: respiratory rate, heart rate, rectal temperature, and lipid mobilization	**Increased:** lipid and protein catabolism, SOD, catalase GPx and lipid peroxidase activities, protein oxidation, lymphocyte mortality, rectal temperature, respiratory rate, pulse and skin temperature, blood urea nitrogen, uric acid, creatinine, alanine transaminase, aspartate transaminase, sodium and potassium, cortisol hormone, osmotic fragility of erythrocytes	
Reproduction	**Reduced:** sperm quality, libido, testosterone levels, follicular growth, oocyte maturation, concentrations of estradiol in the follicles, and primary cultures of granulosa cells	**Reduced:** sperm quality, percentage of epididymal spermatozoa, ovulation rate, embryo production, plasma estradiol levels, sexual behavior ewe	Hamilton et al., 2016 Rathwa et al., 2017 Li et al., 2018 Aleena et al., 2018 Kumar et al., 2019
	Increased: FSH and LH secretion	**Increased:** sperm GPx enzyme activity	
Milk and meat production	**Reduced:** milk yield, fat content, protein, and lactose contents and body weight, pre-slaughter weight, hot carcass weight, separable fat and fat mass index, meat flavor, texture	**Reduced:** milk yield, fat content, protein content, and carcass weight	Salama et al., 2014 Archana et al., 2018 Salama et al., 2020
	Increased: HSP70 in meat	**Increased:** darkening, odor, taste, water retention, and microorganism susceptibility	

SOD: superoxide dismutase; GPx: glutathione peroxidase; LH: luteinizing hormone; FSH: follicle-stimulating hormone

EFFECT OF CLIMATE CHANGE ON REPRODUCTION IN SHEEP AND GOAT

The impact of climate change on the reproduction of sheep and goats, including rams, bucks, ewes, and does, is multifaceted and significant (Table 1). One primary concern is the effect of heat stress on reproductive variables, which varies not only between different breeds but also among individual animals within the same breed.

In rams and bucks, heat stress can lead to testicular degeneration and reduced sperm quality (Mohamed et al., 2023; Ben Moula et al., 2024). Elevated body temperature during periods of high ambient temperature increases testicular metabolism without a corresponding increase in blood supply, resulting in local hypoxia and tissue damage (Rocha et al., 2015; Benmoula et al., 2017). This alteration in the spermatogenesis process and reduction in sperm quality include an increase in dead spermatozoa, tailless spermatozoa, and (deoxyribonucleic acid) DNA fragmentation. Furthermore, heat stress can disrupt testosterone production, leading to a decline in circulating testosterone concentrations, which may impact mating behavior and fertility (Niyas et al., 2017).

Scrotal circumference and testicular morphology serve as reliable indicators of sperm production capacity. However, heat stress can lead to the degeneration of the germinal epithelium and partial atrophy in seminiferous tubules, resulting in reduced testicular size and weight.

Spermatogenesis is disrupted by the elimination of germ cells and the degeneration of Leydig and Sertoli cells, primarily due to hypoxia-induced oxidative stress (Shadmehr et al., 2018). While spermatogonia are less affected by heat stress, spermatocytes, and spermatids are relatively more susceptible (Ranjan et al., 2020).

Following heat exposure, changes in seminal attributes occur gradually, with significant effects observed 7 to 14 days post-exposure (Barragán et al., 2023). Seminal degeneration, reduced sperm output, decreased motility, and an increased percentage of morphologically abnormal spermatozoa are common outcomes. However, reports on the direct effect of heat stress on semen quality are conflicting (Benmoula et al., 2017; Badi et al., 2018).

In ewes and does, climate change can disrupt seasonality, affecting breeding patterns and reproductive success (Dobson et al., 2012; Amitha et al., 2019). Heat stress during summer months negatively impacts fertility by reducing the duration and intensity of estrus, altering hormone secretion, and decreasing the fertilization rate (Duarte et al., 2010). Exposure to high temperatures around breeding time can lead to a lower percentage of fertilized ova, decreased conception rates, and increased embryonic abnormalities (Al-Dawood, 2017).

THERMOREGULATORY MECHANISMS

The thermoregulatory mechanisms in sheep and goats are finely tuned to maintain their core body temperature within a narrow range conducive to normal physiological functions (Farias Machado et al., 2020). To sustain optimal production levels, these animals must maintain relatively constant body temperature across diverse environmental conditions while minimizing additional energy expenditure (Al-Tamimi, 2007). Small ruminants exhibit a plethora of adaptive responses to counteract the direct and indirect impacts of heat stress in tropical regions, including modified behaviors and physiological processes aimed at maintaining thermal equilibrium (Lima et al., 2022).

Physiologically, small ruminants enhance respiratory rate, sweating rate, and pulse rate to facilitate heat dissipation. Moreover, changes in the biochemical profile occur, with alterations in hematocrit values, haemoglobin levels, and blood concentrations of glucose, protein, cholesterol, and non-esterified fatty acids (Rahardja et al., 2011).

At the molecular level, heat stress triggers the upregulation of heat shock proteins (HSPs) in small ruminants, which act as intra-cellular chaperones to prevent protein and cell damage (McManus et al., 2022). Studies have shown increased expression of various HSP genes in response to heat stress, indicating a molecular mechanism for cellular protection (Ravindranathan et al., 2017). Additionally, heat stress impacts immune cell activity, with alterations in cytokine gene expression and reduced expression of intracellular toll-like receptors (TLRs) in heat-stressed animals. Hormonal regulation also plays a crucial role in thermoregulation and metabolic adjustments during heat stress, with hormones such as prolactin, cortisol, and thyroid hormones orchestrating adaptive responses (Rout et al., 2016).

Prolactin, for instance, serves a multifunctional role in thermal acclimatization and water conservation under hot conditions (Bhimte et al., 2018). Elevated levels of prolactin are observed in response to heat stress across various ruminant species, suggesting its role as a reliable marker of heat stress. Conversely, depressed thyroid activity is a characteristic feature of heat stress in small ruminants, leading to reduced metabolic activity and rumen motility. Other hormones such as leptin, adiponectin, growth hormone, mineralocorticoids, and antidiuretic hormone (ADH) also contribute to thermal adaptation in small ruminants (Hooper et al., 2020).

THE ADVANTAGES OF GOATS COMPARED TO SHEEP IN THE LIGHT OF CLIMATE CHANGE

Goats possess several advantageous traits compared to sheep, particularly in the context of climate change adaptation. These advantages are rooted in their unique physiological, morphological, and behavioral adaptations to environmental stressors (Nair et al., 2021).

Firstly, goats are homeothermic animals, capable of actively regulating their body temperature to maintain thermal balance (Ferreira et al., 2021). This ability is crucial for animals exposed to fluctuating environmental temperatures, particularly in regions affected by climate change. Additionally, goats demonstrate a remarkable capacity for heat dissipation, facilitated by their enlarged ears, extensive vascular network, and thin skin, which increase surface area for efficient heat loss (Piccione et al., 2005). This adaptation is particularly evident in some goat breeds inhabiting arid and semi-arid regions, where high ambient temperatures and low relative humidity prevail.

Furthermore, goats exhibit thermoregulatory behaviors tailored to their environmental conditions. For instance, in response to hot and dry conditions, goats tend to travel shorter distances and rest more during the hottest hours of the day (Araújo do Nascimento et al., 2022). They also employ evaporative cooling mechanisms such as extending their tongues, which helps lower body temperatures through evaporative heat loss (Hoffmann, 2013). These behavioral adaptations help goats to be more thermotolerant and resilient in environments with high temperatures and low humidity.

Goats possess several morphological traits that are crucial for managing heat stress and optimizing efficiency in extreme climatic conditions. Their narrower muzzles and split upper lips enhance their ability to selectively forage, which can be critical in environments with scarce resources. Additionally, coat color plays a vital role in thermoregulation, with lighter-colored goats showing lower rectal temperatures and reduced heat stress indices compared to darker-colored ones (Berihulay et al., 2019). This is due to the reflective properties of lighter coats that minimize heat absorption and help maintain cooler body temperatures.

Furthermore, the variability in body sizes among goat breeds is an adaptive feature for different climatic zones. In hot and humid environments, smaller-bodied breeds (dwarfs) are advantageous due to their lower metabolic heat production and higher surface area-to-volume ratio, which aids in heat dissipation (Leite et al., 2021). Conversely, larger-bodied breeds are more suited to regions with significant temperature fluctuations, benefiting from their greater thermal inertia and insulating properties.

Goats also support sustainable agricultural practices by contributing to reduced environmental pollution and greenhouse gas emissions compared to intensive livestock systems. Their efficient feed conversion, resilience to adverse conditions, and ability to thrive on marginal lands help mitigate the adverse impacts of climate change on livestock production systems (Nair et al., 2021). These traits underscore their role in enhancing production efficiency and resilience in challenging environments

CONCLUSION

The review highlights the urgency of addressing the challenges posed by climate change on sheep and goat production. The impacts of extreme heat on animal health, reproduction, and productivity jeopardize the economic viability of livestock farming. Furthermore, the variation in climatic conditions leads to significant disruptions in milk production and meat quality, exacerbating economic pressures on farmers.

However, despite these challenges, adaptation and proactive management strategies can be implemented to mitigate the adverse effects of climate change. Understanding the physiological mechanisms of heat response, as well as the adaptive advantages of goats over sheep, provides valuable insights for developing resilient and sustainable farming practices. It is imperative to implement measures to enhance herd resilience to extreme weather conditions, including improving access to water and balanced nutrition, optimizing pasture management practices, and promoting the use of animal breeds adapted to changing environments.

Lastly, collaboration among farmers, researchers, policymakers, and industry stakeholders is essential to develop and implement innovative and sustainable solutions to ensure food security, preserve the livelihoods of rural communities, and promote environmental sustainability in the face of increasing climate change.

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