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Review

Evaluation of Climate Change on the Growth and Reproductive Performance of Sheep - A Review

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Abstract

Climate change presents considerable challenges for sheep production, negatively impacting growth performance, reproductive efficiency, and the overall sustainability of flocks. Increased temperatures, feed shortages, high C4 vegetation, and a rise in disease prevalence due to changing climate patterns have resulted in production losses within sheep farming systems. This review examines the genetic, physiological, and management adaptations that can help alleviate the effects of climate stress on sheep. It discusses key genetic markers associated with heat tolerance, metabolic efficiency, and reproductive resilience, highlighting the importance of selective breeding in improving climate adaptation. Furthermore, it assesses nutritional and management strategies, such as enhanced feeding practices and environmental adjustments, as potential solutions to maintain sheep productivity in evolving climates. Gaining insight into these adaptation mechanisms is essential for creating sustainable livestock systems and ensuring the resilience of sheep production in the face of future climate challenges.

Keywords: Adaptive Breeding, Genetic Resilience, Livestock Sustainability, Reproductive Efficiency, Thermal Stress.

Introduction

Climate change represents a significant global threat to ecosystems, with predictions suggesting that abnormal weather patterns may lead to the elimination of up to 8% of animal species (Pachauri & Mayer, 2014). Livestock production, especially grazing animals like sheep, is highly vulnerable to climate-induced stressors, including thermal stress, changes in pasture quality and quantity, and increased pests and diseases. These factors in concert threaten both livestock productivity and animal welfare (Baumgard *et al*., 2012). Extreme weather, temperature rise, and shifting rainfall patterns pose very serious risks to the sustainability of livestock, significantly impacting sheep performance growth, reproduction, and production (Pilling & Bélanger, 2019).

Recent studies have shown that climate change affects the productivity and reproduction of sheep through changes in feed availability, water supply, disease prevalence, and temperature-induced stress (Thornton *et al.*, 2022). To develop effective mitigation strategies, it is crucial to understand the direct and indirect impacts of climate change on livestock systems. The impacts can be minimized by using a comprehensive approach that includes forecasting and adaptive strategies (Thornton *et al*., 2009). Such one approach will be genetic selection for breeds that have shown resilience to extreme climatic conditions in livestock (Baumgard *et al.*, 2012).

Sheep are particularly vulnerable to climate-induced stressors due to their dependence on pasture-based systems, which are directly influenced by environmental changes *(*Gowane *et al.*, 2017). Heat stress significantly reduces feed intake, disrupts metabolic processes, and weakens immune responses, resulting in diminished productivity and increased mortality rates (McManus *et al*., 2020). Moreover, changes in climate impact reproductive cycles, conception rates, and lamb survival, which are critical for the sustainability of sheep farming (Nel *et al*., 2023).

The continuity of conventional sheep production systems is compromised by such environmental stressors as prolonged droughts, heat waves, and erratic rainfall, which call for adaptation measures that can help to maintain productivity. Various mitigation strategies are being investigated by researchers and livestock producers, including genetic selection for climate resilience, nutritional interventions, and improved practices in livestock management. (Grossi *et al*., 2019). This review assesses the impacts of climate change on growth and reproductive performance in sheep, emphasizing key physiological, genetic, and management adaptations that can mitigate these impacts.

Sheep Production and Climate Change

The Role of Sheep in Contributing to Climate Change

Sheep farming significantly contributes to climate change through greenhouse gas (GHG) emissions, primarily methane (CH_4) and nitrous oxide (N_2O). Enteric fermentation in sheep produces methane, which has a global warming potential 21 times higher than carbon dioxide (Biswas *et al*., 2010). Additionally, manure decomposition releases both methane and nitrous oxide, further exacerbating emissions. Studies indicate that on-farm activities, including pasture management and transportation, also contribute to the carbon footprint of sheep production (Bell *et al*., 2012).

Sheep produce methane as a by-product of digestion and pasture-based systems of sheep will have greater emissions than sheep in more intensive systems due to their lower feed conversion. According to Biswas *et al*. (2010), the GHG footprints from sheep meat and wool production in Australia is significant, with methane being the main emission. Furthermore, Bell *et al*. (2012) point out that warming temperatures, coupled with changes to forage digestibility in the future climate scenarios may lead to increased methane emissions, influencing sheep metabolism and digestion.

Nitrous oxide emissions results from complex interactions between manure and soil processes during which nitrogen present in animal waste materials undergoes microbial transformation. The process experiences significant intensification within pasture-based grazing systems which results in considerable emissions of N_2O (Bell *et al*., 2012). The critical concern surrounding these emissions arises from nitrous oxide's exceptional warming potential, which exceeds that of carbon dioxide by a factor of 310.

Life Cycle Assessment (LCA) methodologies demonstrate that sheep farming operations generate significant environmental affects due to their substantial methane and nitrous oxide emissions. The research conducted by

Biswas *et al* (2010) demonstrates that wool production generates more greenhouse gases per kilogram than meat production because wool-producing sheep have longer lifespans. The LCA approach demonstrates that emissions produced directly on farms through processes such as enteric fermentation and manure management become the predominant factors in the overall emissions profile associated with sheep farming.

Table 1 shows global GHG emissions from sheep production over different years. Methane (CH_4) from enteric fermentation is the largest contributor, peaking in 1991 and changing over time. CH_4 and nitrous oxide (N_2O) emissions from manure management have shown a gradual increase. These trends reflect changes in sheep production and manure management practices (FAO, 2025).

Table 1: Global GHG emission from sheep in different years (in kiloton).

Source	GHG	Year	Estimated value (in kilo ton)
Enteric fermentation	CH4	1961	6474.0274
	CH4	1971	6885.6234
	CH4	1981	7012.1612
	CH4	1991	7492.3972
	CH4	2001	6112.044
	CH4	2011	6308.7764
	CH4	2021	7177.362
	CH4	2022	7275.8699
Manure management	CH4	1961	178.1621
	CH4	1971	191.2418
	CH4	1981	192.5895
	CH4	1991	208.94
	CH4	2001	175.2454
	CH4	2011	181.1194
	CH4	2021	206.5155
	CH4	2022	209.4083
	N2O	1961	11.1038
	N2O	1971	11.5294
	N2O	1981	12.4092
	N2O	1991	13.0328
	N2O	2001	9.3501
	N2O	2011	10.2222
	N2O	2021	11.8442
	N2O	2022	12.0132

(Source: FAOSTAT, 2025, https://www.fao.org/faostat/en/#data).

Climate Change and Sheep Growth Performance

Heat Stress and Growth Rate

Climate change presents a significant threat to sheep production, primarily through heat stress, which adversely affects their growth performance (Ben Moula *et al*., 2024; Joy *et al*., 2020). Sheep, like other livestock, are susceptible to high temperatures, which can compromise their physiological equilibrium and diminish their production and reproduction efficiency (Ben Moula *et al*., 2024).

Sheep are highly susceptible to heat stress, which leads to reduced feed intake, altered metabolic function, and impaired growth rates. Elevated temperatures cause an increase in water intake and a decline in dry matter consumption, reducing body weight gain and average daily growth (McManus *et al*., 2020). Heat stress also disrupts rumen fermentation, affecting nutrient absorption and feed efficiency. Additionally, chronic heat stress suppresses the activity of digestive enzymes, negatively impacting nutrient absorption (Tüfekci & Sejian, 2023).

Changes in temperature and humidity directly impact milk and meat production in sheep, affecting productivity and product quality (Ben Moula *et al*., 2024). Elevated temperatures can detrimentally affect milk yield in sheep breeds; for example, Comisana sheep can experience a 20% decline in milk production when temperatures exceed 35°C, while Sarda sheep may experience a 30% decrease in milk yield when temperatures exceed 21 to 24°C (Ben Moula *et al.*, 2024). High temperatures can lead to immediate reductions in milk production, fat, and protein yields (Ben Moula *et al*., 2024).

Feed Availability and Nutritional Challenges

Climate change has a significant impact on the productivity and quality of pastures. Rising temperatures and drought conditions lead to a decrease in forage availability, which can cause nutritional deficiencies and reduced energy intake for sheep. Additionally, changes in vegetation composition affect grazing patterns and the overall health of the animals (Gowane *et al.*, 2017). The amount and quality of forage accessible for sheep grazing are directly influenced by climate variability, especially in areas facing drought and shifting precipitation patterns. Decreased rainfall and increased temperatures contribute to pasture degradation, resulting in less feed availability and nutrient deficiencies (Karthik *et al*., 2021). As a result, sheep producers often have to depend on supplementary feeding, which raises production costs and environmental impacts. Research indicates that implementing climate-adaptive grazing management and selecting improved pasture species can help alleviate these challenges (Bell *et al*., 2012).

Heat stress results in lower feed intake and higher water consumption, leading to changes in hormonal balance, increased maintenance needs, and decreased overall performance (Sejian *et al*., 2016). Environmental stressors can also lead to weight loss, reduced daily gains, and poorer body condition in livestock (Sejian *et al.*, 2016). Extreme weather events driven by climate change, such as heat waves and droughts, present a significant risk to sustainable agricultural production (Habib-ur-Rahman *et al*., 2022). Additionally, climate change can indirectly impact livestock by diminishing both the quantity and quality of available forage. Heat stress can lower the protein and starch levels in grains used for feed (Habib-ur-Rahman *et al*., 2022). Other climate-related issues, including cyclones, droughts, heavy rainfall, and erratic weather patterns, can also adversely affect sheep farming (Gowane *et al*., 2017). Water shortages, worsened by climate change, threaten food security and the productivity of animal agriculture (Assan, 2022).

Disease Prevalence and Growth

Increasing temperatures and humidity provide ideal conditions for parasites and infectious diseases that hinder sheep growth. For instance, gastrointestinal parasites flourish in warmer environments, resulting in higher infection rates and decreased growth performance (Van Wettere *et al*., 2021). To combat this, implementing effective parasite management strategies, such as rotational grazing and selecting for genetic resistance to diseases, is crucial for sustaining healthy sheep populations. Elevated parasite loads contribute to slower growth rates due to diminished feed efficiency and weakened immune responses (Dwyer & Lawrence, 2005).

Impact of Climate Change on Reproductive Performance

Fertility and Conception Rates

Climate change significantly affects sheep reproduction, particularly due to heat stress. Rising temperatures disrupt estrous cycles, leading to a 15–25% reduction in conception rates when ewes are exposed to heat stress above 32°C (Van Wettere *et al*., 2021). Reproductive efficiency in sheep is highly sensitive to thermal stress, as heat stress negatively impacts follicular development and embryo survival, leading to lower reproductive success rates (Nel *et al*., 2023).In rams, prolonged exposure to heat stress reduces sperm motility, viability, and overall quality, with sperm motility declining by 20–35% at temperatures exceeding 35°C (Tüfekci & Sejian, 2023). This decline in fertility has direct consequences on lambing success and flock sustainability. Additionally, heat stress impairs endocrine function, reducing levels of reproductive hormones such as progesterone and estrogen, which are essential for successful fertilization and pregnancy maintenance. Sheep subjected to extreme heat conditions exhibit increased cortisol levels, leading to suppressed reproductive activity (Van Wettere *et al*., 2021).

Studies indicate that prolonged exposure to high temperatures results in irregular estrous cycles, lower conception rates, and increased embryonic loss (Rahim & El Amiri, 2023). The cumulative effects of these disruptions result in lower fertility rates and decreased reproductive success, threatening the long-term sustainability of sheep production systems.

Impact on Semen Quality and Male Fertility

Male fertility is significantly impacted by heat stress, leading to testicular degeneration, reduced sperm motility, and increased abnormal sperm morphology. Rams exposed to high heat conditions during mating seasons produce lower semen volumes with decreased sperm viability and motility (Sejian *et al.*, 2012).

Furthermore, excessive heat disrupts spermatogenesis by impairing Sertoli cell function, leading to reduced testosterone production and poor semen characteristics (Barragán Sierra *et al*., 2021). The oxidative damage caused by heat stress can also increase lipid peroxidation in sperm membranes, leading to decreased sperm viability and fertilization capacity (George *et al*., 2020). Collectively, these factors contribute to lower reproductive efficiency in rams, which in turn affects overall flock fertility.

Lambing and Neonatal Survival

Heat stress during gestation negatively impacts fetal development, leading to a 10–20% reduction in lamb birth weights when ewes experience high temperatures (above 30°C) in the last trimester of pregnancy (Karthik *et al*., 2021). Heat stress during late gestation results in reduced birth weights and increased lamb mortality due to dehydration and thermoregulatory challenges (Dwyer & Lawrence, 2005). Additionally, extreme heat increases the risk of premature births and weak offspring, further compromising lamb survival rates.

Studies show that perinatal mortality can rise by 15–30% under high heat and humidity conditions, as maternal behavior is affected, reducing the ability of ewes to care for their lambs (Bell *et al.*, 2012). The ability of lambs to survive and thrive depends on proper maternal care, which is often disrupted under extreme heat stress.

Pregnancy and Fetal Development under Heat Stress

Heat stress during pregnancy poses a substantial risk to fetal development and lamb survival. Pregnant ewes exposed to high temperatures experience increased abortion rates, stillbirths, and lower birth weights (Lacetera, 2019). Additionally, heat stress leads to placental insufficiency, reducing nutrient and oxygen supply to the developing fetus. Studies have shown that lambs born to heat-stressed ewes have lower weaning weights and increased mortality rates due to weakened immune function (Starič & Cincović, 2024). A study on Ethiopian sheep breeds found that heat stress affects maternal health, resulting in poor milk production, further compromising lamb growth and survival (Tesema *et al*., 2025).

Thermoregulatory and Metabolic Adaptations

Nowadays, heat stress is a significant concern in the ever-changing climatic scenario. It is well known that heat stress affects ruminant animals, particularly through decreased reproduction, growth, and production, increased health issues and mortality. Behavioral, morphological, physiological, and genetic bases are among the key adaptation mechanisms of small ruminants that respond in heat-stressed environments.

Morphological adaptations are physical changes that occur over many generations of animals that enhance its fitness in a given environment. Body size and shape, coat and skin color, hair type, and fat storage are among the main morphological adaptation in sheep (Chedid et al., 2014). Some of the outstanding phenotypic and or genetic adaptations are shown in Table 2.

Table 2: shows morphological adaptations of sheep.

Key Morphological Characteristics	Animal	Reference
Loose coarse wool and Adipose tissue reserves	Awassi sheep	(Gootwine, 2011)
Fat-tail	Damara sheep	(Pourlis, 2011)
Coat color	Massese, Xalda and Soay sheep	(Fontanesi *et al*., 2011)
Skin pigmentation	Barki sheep and goat	(Kim *et al*., 2016)

Genetic Adaptations to Climate Stress in Sheep

Selective breeding offers a potential mitigation strategy for climate-induced reproductive challenges. Studies indicate that certain sheep breeds exhibit genetic resilience to heat stress, possessing traits such as improved thermoregulation and reproductive efficiency under high-temperature conditions (Nel *et al*., 2023). Genomic selection for heat-tolerant breeds presents a viable adaptation approach to sustain reproductive performance in changing climates.

Genetic Markers of Climate Adaptation

Specific genomic regions associated with climate resilience have been pointed out by various studies in sheep. Tsartsianidou *et al*. (2021) conducted a genome-wide scan of Mediterranean breeds of sheep for the identification of genomic regions of heat tolerance and resilience of milk production. More interestingly, a region on chromosome 5 was significantly associated with resilience against temperature fluctuation and included genes belonging to olfactory receptor complexes playing an important role in respiratory evaporation and stress responses (Tsartsianidou *et a*l., 2021).

On a related note, Lv *et al*. (2014) detected 230 SNPs connected with climate-driven selection within a global perspective involving 32 breeds of autochthonous sheep. The findings indicated enrichment, mainly in the genes responsible for regulating energy metabolism, endocrine functions, and immune responses of sheep; in essence, to bear up under the extremities of temperatures in metabolic and physiological ways (Lv *et al*., 2014).

Studies indicate that heterozygosity provides a significant impetus toward adaptation to climate change. High genetic diversity allows populations of sheep to maintain their fitness through changing conditions in the environment. Lv *et al*. (2014) identified heterozygous genomic regions associated with stress resistance thus acting protectively against temperature extremes.

Tsartsianidou *et al*. (2021) also identified the presence of selective pressures that favoured genetic heterozygosity in certain chromosomal regions of Mediterranean dairy sheep, which better adapt to temperature fluctuations. These results confirm the importance of considering genetic diversity in the selection schemes of sheep to be more resilient against climate change.

Climate stress affects energy metabolism and immune function in sheep. Energy use under thermal stress is regulated by GTPase regulator genes, while immune-related genes like TLR and cytokine receptors enhance the resistance to pathogens for survival in different climates (Lv *et al*., 2014).

Understanding the genetic basis of climate adaptation in sheep is important to inform selective breeding programs. Inclusion of traits that confer resilience to climate, such as heat tolerance, metabolic efficiency, and immune resilience, will contribute to raising the sustainability of sheep production in various climate change scenarios. Further research efforts should be focused on integrating genomic selection tools into traditional approaches with the aim of enhancing the adaptive potential of sheep breeds worldwide (Lv *et al.*, 2014; Tsartsianidou *et a*l., 2021).

Mitigation Strategies for Climate Change Adaptation

Strategies to Reduce Emissions from Sheep Farming

To mitigate GHG emissions from sheep production, several strategies have been proposed. Dietary interventions, such as improving forage quality and incorporating feed additives, can reduce methane emissions from enteric fermentation (Bell *et al*., 2012). Additionally, rotational grazing and optimized manure management practices help lower nitrous oxide emissions.

Genetic selection for low-methane-emitting sheep breeds presents another promising approach. Selective breeding programs have shown that certain genetic traits enable sheep to produce less methane while maintaining productivity (Biswas *et al*., 2010).

Furthermore, sustainable pasture management practices, including legume integration and soil carbon sequestration techniques, can offset emissions by enhancing carbon storage in soils (Bell *et a*l., 2012). Policy interventions, such as carbon pricing and incentives for low-emission livestock production systems, may further drive the adoption of sustainable sheep farming practices.

Nutritional Interventions

Supplementing heat-stressed sheep with energy-dense diets, improved forage varieties, and feed additives enhances resilience to climate variability. Nutritional interventions help maintain growth rates and reproductive efficiency in challenging environmental conditions (Gowane *et al*., 2017).

Management Practices

Providing shade, proper ventilation, and water-cooling systems in sheep housing facilities reduces heat stress and improves overall productivity. Seasonal breeding adjustments, such as mating during cooler months, enhance reproductive success rates (McManus *et al*., 2020).

Climate Change Mitigation Strategies to Improve Growth Performance of Sheep

Climate change poses significant challenges to sheep production worldwide, particularly in High temperatures, insufficient water supply, and erratic rainfalls create stressors that negatively affect the productivity of sheep. This is particularly true for arid and semi-arid regions. In order to improve reproductive and growth rates of sheep in these areas, different solutions have been framed such as genetic modification, alteration of nutrition, housing, healthcare provision, and more.

Selective breeding and integrating genotypes are one of the most potent strategies towards improving the climate adaptive capacity of the sheep. Indigenous breeds such as Malpura, Chokla, Marwari, and Magra are some of the breeds that are noted for high adaptability to harsher environments. Programs revolving around selective breeding have the aim of boosting the heat tolerance capability of the subjects without compromising their primary or secondary productivity traits (Naqvi *et al*., 2017). Besides, using crossbred indigenous heat-tolerant breeds with exotic high-yielding ones enhances productivity and tolerance (Gowane *et al*., 2017). Specific heat stress resistance and disease-tolerant traits are now being developed through molecular breeding technologies, including gene editing systems like CRISPR (Sejian *et al*., 2017).

Nutritional strategies help tackle the difficulties posed by climate change in sheep production. The inclusion of alternative feed sources such as shrubs and trees that can survive drought conditions, addresses seasonal feed deficits. Moreover, tailored feeding programs can be devised for specific seasons to ensure sufficient nutrient provisions during environmental hardships. The addition of antioxidants together with vitamin E, selenium, and zinc into sheep diets improves immune competency and reduces the level of heat stress (Naqvi *et al*., 2017). In addition, high-energy feed grains can be stored through silage production and block feed preparations to be used during the drought period to prevent severe malnutrition and weight loss in sheep (Gowane *et al*., 2017).

Enhancement of housing accompanied by improved environmental management practices is an additional key importance to support sheep productivity under climate frustrate. Sufficient shade together with proper ventilation helps to ease heat stress and increases general welfare of the animals. Farmers can apply cooling methods like mist blowing or sprinkler systems, planting trees, or reducing the stocking rate on the sheep pens to aid in lowering the temperature of the housing environment (Sejian *et al*., 2017).

Proper flooring and drainage systems also assist with providing cleanliness which helps prevent disease outbreaks for heat and humid environments (Gowane *et al*., 2017). An increase in disease prevalence due to climate change leads to the need for more comprehensive health management strategies. The flock needs to be vaccinated and parasite-controlled regularly to preserve flock health and productivity. Assessing body condition scores BCS alongside other metabolic parameters facilitates early diagnosis of health problems and timely treatment (Sejian *et al*., 2017). In hot weather environments, water intake should be sufficient and the quality of drinking water should be clean in order to avert physiological imbalance and dehydration (Gowane *et al*., 2017).

Farming technology is an additional means of improving sheep production under the influence of global warming. The use of weather prediction and grazing permits them to control the schedule of overgrazing as well as provide adequate forage. Tools for precision feeding also help to eliminate waste of feed while increasing overall production (Naqvi *et al*., 2017). Gowane *et al*., 2017, indicate that farmers can now address their health issues promptly as wearable sensors can monitor a farmer's stress level in real-time, which assists farmers in taking proactive measures to mitigate consequences. The combination of natural ventilation with shade provisions and climate-adapted breeding approaches provides effective heat stress mitigation in a sustainable manner (Edwards-Callaway *et al*., 2021).

Mitigation Strategies to Improve Reproductive Performance

To counteract the negative impacts of climate change on sheep reproduction, several adaptive strategies can be implemented. Breeding programs focusing on heat-tolerant sheep breeds can improve resilience to climate-induced stress. For instance, Bonga sheep in Ethiopia have demonstrated better resilience to heat stress due to their genetic adaptability (Tesema *et al*., 2025).

Providing balanced diets with antioxidants and vitamins can help mitigate oxidative stress caused by high temperatures. Nutritional interventions, such as increasing dietary polyunsaturated fatty acids, have been shown to improve reproductive outcomes in heat-stressed ewes. Providing shaded areas, ventilation, and water misting can significantly reduce heat stress effects on both ewes and rams. Research has shown that cooling strategies, such as fans and water sprinklers, can improve reproductive efficiency in heat-exposed sheep (Rahim & El Amiri, 2023).

Adjusting mating periods to cooler months can improve conception rates and fetal survival. Studies indicate that strategic breeding during cooler months results in higher pregnancy rates and better lambing outcomes (Van Wettere *et al*., 2021).The use of reproductive hormones such as gonadotropin-releasing hormone (GnRH) can help regulate estrous cycles in heat-stressed ewes.

Policy and Research Recommendations

Governments and research institutions must prioritize climate-resilient livestock production strategies. Investing in breeding programs for heat-tolerant sheep, improving pasture management, and implementing early warning systems for climate-related livestock threats are critical to ensuring sustainable sheep production (Grossi *et al*., 2019). Policies should also encourage community-based breeding programs that involve smallholder farmers in the selection and conservation of resilient sheep breeds. Additionally, subsidies and incentives for sustainable livestock management practices can support the transition to climate-adaptive breeding systems (FAO, 2015).

Conclusion

Climate change has a significant effect on sheep growth and reproduction by increasing heat stress, limiting food availability, and worsening disease outbreaks. To counter these challenges, it's essential to adopt adaptive strategies like selecting for heat-tolerant genetics, optimizing nutrition, and enhancing management practices. Advances in genetics, such as identifying traits that promote climate resilience, offer a way to breed sheep capable of thriving in harsh conditions. Furthermore, management techniques like climate-sensitive feeding, better housing, and reproductive strategies are crucial for maintaining sheep productivity. Future studies should aim to combine genomic selection methods with traditional breeding approaches and improve sustainable livestock management to protect sheep from the impacts of climate change.

The reduction of animal exposure to extreme climate situations remains vital but the necessity to raise energy consumption and CO_2 emissions is disproven. Natural ventilation together with shade provision and climate-adapted breeding techniques enable farmers to lower heat stress in livestock without needing excessive artificial cooling operations. Climate-controlled housing as a high-energy intervention generates emissions but properly integrated renewable energy sources combined with silvopastoral systems and efficient housing structures minimize their environmental consequences. The goal must revolve around developing livestock systems, which combine climate resilience with sustainability to prevent escalating emissions that worsen climate effects.

Contribution by Authors

All the authors contributed equally to writing the manuscript. The final manuscript was read by all authors and consented to publication.

Conflict of Interests

There is no conflict of interest.

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References

1. Assan, N. (2022). Climate Change Impact on Small-Scale Animal Agriculture: Livestock Water; Food Security in Africa. *Trends Journal of Sciences Research*, *1*(1), 13–39. https://doi.org/10.31586/ujfs.2022.541
2. Barragán Sierra, A., Avendaño-Reyes, L., Hernández Rivera, J. A., Vicente-Pérez, R., Correa-Calderón, A., Mellado, M., Meza-Herrera, C. A., & Macías-Cruz, U. (2021). Thermoregulation and reproductive responses of rams under heat stress. Review. *Revista Mexicana de Ciencias Pecuarias*, *12*(3), 910–931. https://doi.org/10.22319/rmcp.v12i3.5624
3. Baumgard, L. H., Rhoads, R. P., Rhoads, M. L., Gabler, N. K., Ross, J. W., Keating, A. F., Boddicker, R. L., Lenka, S., & Sejian, V. (2012). Impact of Climate Change on Livestock Production. In V. Sejian, S. M. K. Naqvi, T. Ezeji, J. Lakritz, & R. Lal (Eds.), *Environmental Stress and Amelioration in Livestock Production* (pp. 413–468). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-29205-7_15
4. Bell, M. J., Eckard, R. J., & Cullen, B. R. (2012). The effect of future climate scenarios on the balance between productivity and greenhouse gas emissions from sheep grazing systems. *Livestock Science*, *147*(1–3), 126–138. https://doi.org/10.1016/j.livsci.2012.04.012
5. Ben Moula, A., Kchikich, A., Chentouf, M., Hamdache, A., Bouraada, K., Essafi, M., & Ezziyyani, M. (2024). Climate change impacts on sheep and goat production and reproduction. *Journal of Central European Agriculture*, *25*(4), 910–918. https://doi.org/10.5513/JCEA01/25.4.4335
6. Biswas, W. K., Graham, J., Kelly, K., & John, M. B. (2010). Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia – a life cycle assessment. *Journal of Cleaner Production*, *18*(14), 1386–1392. https://doi.org/10.1016/j.jclepro.2010.05.003
7. Chedid, M., Jaber, L. S., Giger-Reverdin, S., Duvaux-Ponter, C., & Hamadeh, S. K. (2014). Review: Water stress in sheep raised under arid conditions. *Canadian Journal of Animal Science*, *94*(2), 243–257. https://doi.org/10.4141/cjas2013-188
8. Dwyer, C. M., & Lawrence, A. B. (2005). A review of the behavioural and physiological adaptations of hill and lowland breeds of sheep that favour lamb survival. *Applied Animal Behaviour Science*, *92*(3), 235–260. https://doi.org/10.1016/j.applanim.2005.05.010
9. Edwards-Callaway, L. N., Cramer, M. C., Cadaret, C. N., Bigler, E. J., Engle, T. E., Wagner, J. J., & Clark, D. L. (2021). Impacts of shade on cattle well-being in the beef supply chain. *Journal of Animal Science*, *99*(2), skaa375. https://doi.org/10.1093/jas/skaa375
10. FAO. (2015). *Climate change and food security: Risks and responses*.
11. FAO. (2025). *Greenhouse gas emissions from livestock. FAOSTAT database*. [Dataset]. https://www.fao.org/faostat/en/#data
12. Fontanesi, L., Dall'Olio, S., Beretti, F., Portolano, B., & Russo, V. (2011). Coat colours in the Massese sheep breed are associated with mutations in the agouti signalling protein (ASIP) and melanocortin 1 receptor (MC1R) genes. *Animal*, *5*(1), 8–17. https://doi.org/10.1017/S1751731110001382
13. George, W., Zoltán, B., András, J., & Szilvia, K. (2020). *Impacts of climate change on sheep genetic diversity: A review*.
14. Gootwine, E. (2011). Mini review: Breeding Awassi and Assaf sheep for diverse management conditions. *Tropical Animal Health and Production*, *43*(7), 1289–1296. https://doi.org/10.1007/s11250-011-9852-y
15. Gowane, G. R., Gadekar, Y. P., Prakash, V., Kadam, V., Chopra, A., & Prince, L. L. L. (2017). Climate Change Impact on Sheep Production: Growth, Milk, Wool, and Meat. In V. Sejian, R. Bhatta, J. Gaughan, P. K. Malik,

S. M. K. Naqvi, & R. Lal (Eds.), *Sheep Production Adapting to Climate Change* (pp. 31–69). Springer Singapore. https://doi.org/10.1007/978-981-10-4714-5_2

16. Grossi, G., Goglio, P., Vitali, A., & Williams, A. G. (2019). Livestock and climate change: Impact of livestock on climate and mitigation strategies. *Animal Frontiers*, *9*(1), 69–76. https://doi.org/10.1093/af/vfy034
17. Habib-ur-Rahman, M., Ahmad, A., Raza, A., Hasnain, M. U., Alharby, H. F., Alzahrani, Y. M., Bamagoos, A. A., Hakeem, K. R., Ahmad, S., Nasim, W., Ali, S., Mansour, F., & El Sabagh, A. (2022). Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. *Frontiers in Plant Science*, *13*, 925548. https://doi.org/10.3389/fpls.2022.925548
18. Joy, A., Dunshea, F. R., Leury, B. J., Clarke, I. J., DiGiacomo, K., & Chauhan, S. S. (2020). Resilience of Small Ruminants to Climate Change and Increased Environmental Temperature: A Review. *Animals*, *10*(5), 867. https://doi.org/10.3390/ani10050867
19. Karthik, D., Suresh, J., Reddy, Y. R., Sharma, G. R. K., Ramana, J. V., Gangaraju, G., Pradeep Kumar Reddy, Y., Yasaswini, D., Adegbeye, M. J., & Reddy, P. R. K. (2021). Farming systems in sheep rearing: Impact on growth and reproductive performance, nutrient digestibility, disease incidence and heat stress indices. *PLOS ONE*, *16*(1), e0244922. https://doi.org/10.1371/journal.pone.0244922
20. Kim, E.-S., Elbeltagy, A. R., Aboul-Naga, A. M., Rischkowsky, B., Sayre, B., Mwacharo, J. M., & Rothschild, M. F. (2016). Multiple genomic signatures of selection in goats and sheep indigenous to a hot arid environment. *Heredity*, *116*(3), 255–264. https://doi.org/10.1038/hdy.2015.94
21. Lacetera, N. (2019). Impact of climate change on animal health and welfare. *Animal Frontiers*, *9*(1), 26–31. https://doi.org/10.1093/af/vfy030
22. Lv, F.-H., Agha, S., Kantanen, J., Colli, L., Stucki, S., Kijas, J. W., Joost, S., Li, M.-H., & Ajmone Marsan, P. (2014). Adaptations to Climate-Mediated Selective Pressures in Sheep. *Molecular Biology and Evolution*, *31*(12), 3324–3343. https://doi.org/10.1093/molbev/msu264
23. McManus, C. M., Faria, D. A., Lucci, C. M., Louvandini, H., Pereira, S. A., & Paiva, S. R. (2020). Heat stress effects on sheep: Are hair sheep more heat resistant? *Theriogenology*, *155*, 157–167. https://doi.org/10.1016/j.theriogenology.2020.05.047
24. Naqvi, S. M. K., De, K., Kumar, D., & Sahoo, A. (2017). Mitigation of Climatic Change Effect on Sheep Farming Under Arid Environment. In P. S. Minhas, J. Rane, & R. K. Pasala (Eds.), *Abiotic Stress Management for Resilient Agriculture* (pp. 455–474). Springer Singapore. https://doi.org/10.1007/978-981-10-5744-1_22
25. Nel, C. L., Van Der Werf, J. H. J., Rauw, W. M., & Cloete, S. W. P. (2023). Challenges and strategies for genetic selection of sheep better adapted to harsh environments. *Animal Frontiers*, *13*(5), 43–52. https://doi.org/10.1093/af/vfad055
26. Pachauri, R. K., & Mayer, L. (Eds.). (2014). *Climate change 2014: Synthesis report*. Intergovernmental Panel on Climate Change.
27. Pilling, D., & Bélanger, J. (2019). *The state of the world's biodiversity for food and agriculture* [Map]. FAO Commission on Genetic Resources for Food and Agriculture.
28. Pourlis, A. F. (2011). A review of morphological characteristics relating to the production and reproduction of fat-tailed sheep breeds. *Tropical Animal Health and Production*, *43*(7), 1267–1287. https://doi.org/10.1007/s11250-011-9853-x
29. Rahim, A., & El Amiri. (2023). Effects of heat stress and chemical pollutants on sheep reproduction and strategies to mitigate them. *Cham: Springer International Publishing.*, 173-185.
30. Sejian, V., Bhatta, R., Gaughan, J., Malik, P. K., Naqvi, S. M. K., & Lal, R. (2017). Adapting Sheep Production to Climate Change. In V. Sejian, R. Bhatta, J. Gaughan, P. K. Malik, S. M. K. Naqvi, & R. Lal (Eds.), *Sheep Production Adapting to Climate Change* (pp. 1–29). Springer Singapore. https://doi.org/10.1007/978-981-10-4714-5_1
31. Sejian, V., Gaughan, J. B., Bhatta, R., & Naqvi, S. M. K. (2016). *Impact of climate change on livestock productivity*. Feedipedia-Animal Feed Resources Information System-INRA CIRAD AFZ and FAO.
32. Sejian, V., Naqvi, S. M. K., Ezeji, T., Lakritz, J., & Lal, R. (Eds.). (2012). *Environmental Stress and Amelioration in Livestock Production*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-29205-7
33. Starič, J., & Cincović, M. R. (Eds.). (2024). *26th International Congress of the Mediterranean Federation for Health and Production of Ruminants FeMeSPRum proceedings: Novi Sad (Serbia), 20th-23th June, 2024*. Poljoprivredni fakultet, Departman za veterinarsku medicinu, Univerzitet u Novom Sadu.
34. Tesema, Z., Getachew, T., Belay, B., Amha, Y., Rekik, M., Rischkowsky, B., Besufkad, S., Abate, Z., Bekele, T., Demissie, T., Solomon, D., & Haile, A. (2025). Impact of climate change on the productivity and adaptation

of Ethiopia's Bonga and Menz sheep breeds. *Livestock Science*, *292*, 105633. https://doi.org/10.1016/j.livsci.2024.105633
35. Thornton, P., Mensah, C., & Enahoro, D. (2022). *Modelling the effects of climate change on livestock: Towards identifying the priorities*.
36. Thornton, P., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, *101*(3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002
37. Tsartsianidou, V., Kapsona, V. V., Sánchez-Molano, E., Basdagianni, Z., Carabaño, M. J., Chatziplis, D., Arsenos, G., Triantafyllidis, A., & Banos, G. (2021). Understanding the seasonality of performance resilience to climate volatility in Mediterranean dairy sheep. *Scientific Reports*, *11*(1), 1889. https://doi.org/10.1038/s41598-021-81461-8
38. Tüfekci, H., & Sejian, V. (2023). Stress Factors and Their Effects on Productivity in Sheep. *Animals*, *13*(17), 2769. https://doi.org/10.3390/ani13172769
39. Van Wettere, W. H. E. J., Kind, K. L., Gatford, K. L., Swinbourne, A. M., Leu, S. T., Hayman, P. T., Kelly, J. M., Weaver, A. C., Kleemann, D. O., & Walker, S. K. (2021). Review of the impact of heat stress on reproductive performance of sheep. *Journal of Animal Science and Biotechnology*, *12*(1), 26. https://doi.org/10.1186/s40104-020-00537-z

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