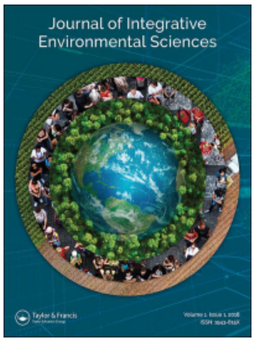

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RESEARCH ARTICLE

Effects of climate change on goat production and mitigatory measures in semiarid savanna ecosystems

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ABSTRACT

Climate change poses a significant threat to goat production in semiarid savannas, disrupting the livelihoods of smallholder farmers who rely on these hardy animals for both income and food security. This review analyses the unique vulnerabilities of goats in this ecosystem, focusing on how rising temperatures, erratic rainfall patterns, and altered vegetation impact their browsing behaviour, feed availability, and overall health. A systematic search of globally indexed scientific databases to identify relevant peer-reviewed literature on the impacts of climate change on goat production in semiarid regions was performed. This review mainly focused on studies published within the last two decades to capture the latest research advancements. Climate change negatively affects goat productivity through decreased availability of high-quality forage, impaired reproductive function due to heat stress, and increased incidence of diseases associated with changing weather patterns. These challenges disproportionately impact smallholder farmers who rely on goats for subsistence and income generation. However, promising mitigation strategies offer hope for building resilience. Emerging practices such as developing heat-tolerant goat breeds and utilizing drought-resistant forage species through selective breeding programmes and ecological restoration initiatives can be enhanced and adopted. Additionally, studies highlight the effectiveness of improved animal husbandry techniques, including strategic water resource management and diversified feed sources, in enhancing goat health and productivity under changing environmental conditions. By quantifying the potential impact of climate change on goat production and highlighting the positive outcomes of novel adaptation techniques, this review emphasizes the urgency of fostering resilient goat farming practices.

HIGHLIGHTS

- Climate change threatens goats with reduced forage and health risks.

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KEYWORDS
Animal welfare; genetic potential; climate action; goat health; drought tolerance; zero hunger

SUSTAINABLE DEVELOPMENT GOALS
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- Rising temperatures and erratic rainfall diminish goat productivity in semiarid regions.
- Promising solutions include heat-tolerant breeds and drought-resistant forage species.
- Recent studies emphasize climate impacts and effective mitigation in goat farming.
- Integrated water management and improved disease control are critical for resilience.
- Urgently adopt sustainable practices to safeguard goat production in changing climates.

1. Introduction

Goat populations worldwide have increased significantly by more than 240% over the last 50 years, while the populations of other livestock species have either remained the same or decreased (Morales et al. 2019). There are currently more than a billion goats around the globe, with the majority of them (more than 94%) being found in Asia (556 million heads) and Africa (388 million heads) (Nguyen et al. 2023). Climate change is a major global issue that seriously impedes agricultural systems worldwide, particularly animal production. The consequences of climate change on goat production are especially noticeable in semiarid savanna habitats, including those found in sub-Saharan Africa, sections of Asia, and South America (Henry et al. 2018). In these areas, goats are valuable livestock because they provide locals with milk, meat, and other useful items (74% of which are smallholder farmers). Climate change, characterized by rising temperatures, erratic precipitation patterns, and more frequent extreme weather events, directly impacts the productivity, health, and sustainability of goat farming in semiarid regions. Conversely, goat production also contributes to and is affected by climate change through various mechanisms, such as greenhouse gas emissions from livestock, land use changes associated with grazing, and adaptation strategies implemented by farmers in response to changing environmental conditions. This strong relationship between climate change and goat production in semiarid savanna habitats has become increasingly important in light of the acceleration of climate change. Given their adaptability, goats are vulnerable to variations in temperature and precipitation, which can have a significant impact on productivity (Jousan and Haddad 2017). Climate change significantly affects goat production in semiarid savanna habitats, manifesting in various ways that challenge the sustainability and productivity of goat farming. Increasing temperatures exacerbate heat stress in goats, diminishing their health and productivity. Erratic rainfall patterns and droughts reduce the quantity and quality of available forage, leading to malnutrition and decreased production. Additionally, climate change creates favourable conditions for parasites, increasing infestation rates and further compromising goat health. These factors can negatively impact reproductive health, growth rates, milk production, and general animal well-being (Jawasreh et al. 2016). It has been suggested that heat stress alone can reduce milk yield in goats by up to 30% (Gupta and Mondal 2021). In addition, estimates suggest that climate change could decrease global goat meat production by as much as 20% by 2050 (Nardone et al. 2010).

The development of comprehensive plans that address each of these elements in an integrated and systematic manner is essential for maintaining sustainability and productivity in the face of these difficulties. For farmers in semiarid savanna ecosystems to effectively adapt to and manage the problems posed by climate change, mitigation strategies are crucial. The introduction of drought-resistant forage species, improved herd management techniques to lessen heat stress, the application of disease control measures, and enhanced water management tactics, such as rainwater gathering and effective irrigation techniques, as highlighted by Cardoso and Rao (2019), are some of these efforts. To mitigate the adverse effects of climate change on ecosystems, a thorough assessment of the numerous variables affecting goat productivity in semiarid areas is therefore warranted. The objective of this review is to comprehensively analyse the impact of climate change on goat production in semiarid habitats and explore effective mitigation strategies. Specifically, this review aims to document and evaluate research conducted over the past twenty years on the effects of climate change on goat productivity. This study sought to understand the multifaceted challenges posed by climate change, including decreased fodder production, water scarcity, and increased disease incidence. Additionally, this review aims to identify and assess various mitigation measures implemented by farmers in semiarid savanna ecosystems, such as the introduction of drought-resistant forage species, improved herd management techniques to mitigate heat stress, disease control measures, and enhanced water management tactics such as rainwater harvesting and efficient irrigation methods.

A systematic literature review was conducted to comprehensively assess the mitigation strategies employed by farmers in semiarid savannas for goat production under climate change. Internationally recognized databases such as Web of Science, PubMed, Scopus, and Google Scholar were searched using a combination of keywords, including "goat production", "production factors", "semiarid production systems", "climate change mitigation", and "climate change impacts on goats". This initial search yielded over 200 research articles. Following PRISMA guidelines, a multistep selection process was implemented to refine the results. Duplicate records were removed, and titles and abstracts were screened to ensure their relevance to goat production in semiarid environments, climate change impacts, and mitigation strategies. Full-text articles retrieved for further assessment were rigorously evaluated based on their direct connection to the research goals. This included a focus on goat production in semiarid savannas, the exploration of farmer-implemented mitigation strategies for climate change, and an emphasis on factors influencing goat productivity under changing climate conditions. Ultimately, only research that directly advanced the understanding of crucial mitigation strategies was included in the qualitative synthesis for analysis. This systematic approach ensured a comprehensive and relevant selection of studies for evaluating how farmers in semiarid savannas had adapted goat production practices to mitigate the challenges posed by climate change. A focused examination of the relevant literature ($n = 112$) was made possible by this methodical selection procedure, and the result was the creation of a theoretical framework (Figure 1) that suggested a more thorough understanding of the relationship between goat production and climate change.

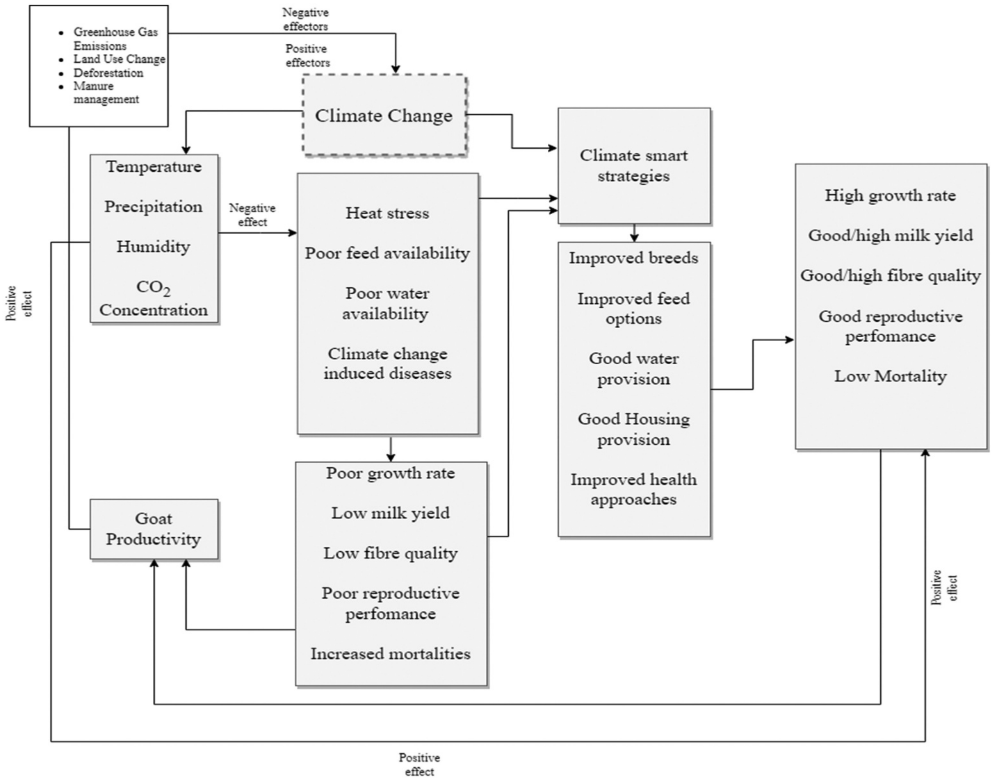

Figure 1. Theoretical framework of the impact of climate change and the effect of climate-smart strategies on goat productivity.

2. Climate change in southern Africa

Climate change is a major challenge in southern Africa, particularly for semiarid regions that are already vulnerable to aridity (Kim et al. 2023). Less regular rainfall patterns are a common effect of climate change and increase the likelihood of long droughts and water scarcity (Dinko and Bahati 2023). The current problem in Lesotho, where a study by Chikoore et al. (2024) revealed a 20% decrease in average rainfall over the previous 20 years, is a classic example. It has been predicted that communities will experience a lack of water as a result of this decline's substantial effects on the drinking water supply, agriculture, and ecosystems (Thakur 2024). A vicious cycle is fuelled by increasing aridity, where higher evaporation rates dry up the land, which deteriorates the soil and increases heat stress on human, animal, and natural systems. Extreme heat events can be dangerous for human and animal health and agricultural output (Dinko and Bahati 2023). Rising temperatures and changes in precipitation patterns upend ecosystems, endangering biodiversity as species try to adapt or lose their habitat (Kim et al. 2023).

Moreover, crop yields, planting dates, and harvesting schedules are affected by climate change, which may result in food insecurity and unstable financial conditions for farmers. Drier weather has led to a rise in wildfire frequency, which puts human communities and ecosystems at risk and has serious ecological and economic consequences (Gajendiran et al. 2023; Moustafa et al. 2023). Increased social and economic vulnerability could result from the compounding effects of climate change, especially for populations that are already vulnerable to food insecurity, health problems, or weather-related relocation (Pasupuleti and Orekanti 2024). Therefore, it is essential to comprehend these cascading effects to develop effective mitigation and adaptation strategies.

3. Climate variability and goat production

Climate variability, characterized by fluctuations in temperature, precipitation patterns, and the increased frequency of extreme weather events, poses a significant threat to goat production systems worldwide. These variations disrupt the delicate balance between goats, their environment, and the resources they rely upon. One of the most immediate impacts of climate variability is a decrease in fodder availability. Prolonged droughts and erratic rainfall patterns lead to dry pastures, directly impacting the quantity and quality of feed accessible to goats (Muruganandam et al. 2023). This scarcity of essential nutrients results in slower growth rates, reduced milk production, and a decline in the overall nutritional health of goat herds. For instance, limited access to fresh forage can lead to deficiencies in essential vitamins and minerals, compromising their immune function and overall well-being (Sebata 2018).

The rising temperatures associated with climate change pose another major challenge for goat production. Goats struggle to regulate their body temperature during extreme heat events, leading to heat stress (Kumalo and Manyani 2023). This stress manifests in several ways, including reduced feed intake, decreased fertility, and increased health problems. Heat stress further compromises their nutritional intake as goats lose their appetite and disrupt hormonal cycles, leading to lower conception rates and reproductive problems (Kumalo and Manyani 2023). Additionally, a weakened immune system due to heat stress increases the susceptibility of goats to various health issues. Recent studies by Sejian et al. (2021) have shown that prolonged exposure to high temperatures increases the risk of infectious diseases such as mastitis and respiratory infections in goats. Moreover, heat stress can exacerbate existing health conditions, leading to increased mortality rates and decreased productivity among goat herds (Machado 2018). These detrimental effects highlight the urgent need for adaptive measures to mitigate the impacts of climate variability on goat production.

Water scarcity, often exacerbated by climate variability, poses another significant threat. Goats require consistent access to clean water for proper digestion, thermoregulation, and overall health (Kumalo and Manyani 2023). When water becomes scarce, dehydration can lead to a range of health problems, including kidney failure, digestive issues, and reduced milk production in lactating does (Kumalo and Manyani 2023). Climate change can also alter the dynamics of diseases that affect goats. Rising temperatures and erratic weather patterns can create favourable conditions for disease vectors, increasing the risk of outbreaks (Yadav et al. 2023). Additionally, erratic rainfall and temperature fluctuations can disrupt the breeding cycles of goats, leading to lower conception rates and greater infant mortality due to stress-induced weakening of offspring (Yadav et al. 2023).

4. Factors influencing goat productivity

4.1. Nutrition

Nutrition is a limiting factor of livestock production in semiarid areas, which are characterized by declines in rangeland productivity due to frequent droughts, variability, and climate change (Bett et al. 2017; Timpong-Jones et al. 2023). According to Nipane et al. (2023), goats consume an average of 3% of their body weight (3.5–4% for meat goats and 4–6% for dairy goats). Grazing resources are greatly influenced by the seasonality of rainfall; hence, low-quality crop residues are the main supplementary dry-season feed. Fodder crops are an alternative feed source. However, they are expensive and not readily available, and they are mostly based on staple food crops such as maize, thus creating competition between livestock and humans (Wilkinson and Lee 2018). Therefore, Indigenous browse species in rangelands remain a significant source of persistent and abundant animal feed (Mudzengi et al. 2020).

4.2. Animal health

Climate change poses a significant threat to animal health in goat production systems, particularly those situated in semiarid regions (Kumalo and Manyani 2023). Rising temperatures, altered precipitation patterns, and the increased frequency of extreme weather events create a cascade of negative effects. Heat stress is a major concern, as goats struggle to regulate their body temperature in extreme heat, leading to reduced feed intake, decreased milk production, and impaired reproductive performance (Kumar et al. 2018). This decline in feed intake due to heat stress compromises overall nutritional intake, while hormonal disruptions associated with heat stress can lead to lower conception rates and reproductive problems (Das et al. 2016). Lactating does also experience decreased milk production as a result of reduced energy intake. Health challenges are also exacerbated by impacting the quality and quantity of available forage. Changes in vegetation growth patterns due to altered precipitation and temperature regimes can lead to a decrease in the nutritional value of forages (Koluman 2023). This limited access to essential nutrients further weakens the immune system of goats, increasing their susceptibility to various diseases (Singh 2023).

Water scarcity, another consequence of climate change, further complicates this situation. Altered precipitation patterns and increased evaporation rates can limit access to clean and sufficient water (Ndlela 2016). Water scarcity-induced dehydration not only weakens goats but also increases their susceptibility to diseases such as mastitis, a bacterial infection of the udder (Ramesh et al. 2014). Additionally, Bett et al. (2017) highlighted that climate change can influence the distribution and prevalence of diseases and parasites. Rising temperatures and erratic weather patterns can create favourable conditions for disease vectors such as ticks and mosquitoes, increasing the risk of outbreaks of infectious diseases such as heartwater and babesiosis in goat populations (Perry 2002).

4.3. The socioeconomic impact

It is quite concerning how climate change may affect semiarid goat producers, with far-reaching ramifications for these communities. Climate change poses a significant threat to the livelihoods of semiarid goat farmers. Rising temperatures, prolonged droughts, erratic rainfall patterns, and extreme weather events are creating a cascade of negative socio-economic consequences (Phiri et al. 2020). One of the most immediate effects of climate change is a decrease in fodder availability. Droughts and limited vegetation growth make it difficult to adequately feed goat herds (Leweri 2022). This reduction in the quality and quantity of forage directly impacts goat productivity, leading to lower milk yields, slower growth rates, and decreased income for farmers. Water scarcity is another major challenge. Changing precipitation patterns and increased evaporation rates make it difficult for farmers to secure consistent water supplies for their goats (Ndlela 2016). Water is crucial for goat health and productivity (Nipane et al. 2023). Scarcity not only affects animal well-being but also increases the labour and financial costs associated with water acquisition. Goats require more water during extreme heat, further straining already limited resources.

Climate change aggravates existing challenges for farmers. Increasing input costs (e.g. feed supplements) and increased healthcare needs due to climate-related health issues in goats can put significant strain on their finances (Sejian et al. 2021). The combined effects of climate change can lead to long-term economic hardship for goat farmers, making it difficult for them to recover from losses. Furthermore, declining goat productivity threatens the supply of milk and meat, which are vital sources of nutrition in many semiarid communities. In extreme cases, climate disasters can force goat farmers to migrate or relocate, disrupting communities and severing cultural ties (Phiri et al. 2020). The impact of climate change goes beyond just the economic sphere. It can also affect the cultural practices and traditions of pastoralist communities that rely on goats. Changes in goat productivity and potential shifts in the cultural value placed on these animals can have a significant impact on their way of life.

4.4. Genetic factors

Goat production in semiarid areas is strongly influenced by genetic factors. These variables include breed selection, local environment adaptation, and features that directly affect productivity (Arenas-Báez et al. 2023). A key step is to first choose breeds of goats that have a reputation for being hardy in dry environments. Genetic modifications to tolerate heat, drought, and scarce resources can also emerge over time (Lu 2023). Hereditary factors have a significant impact on production in terms of reproductive characteristics, growth rates, and illness resistance (Wanjala et al. 2023). In these difficult settings, breeding for higher reproductive rates, quicker growth, and better meat or milk quality can considerably increase the economic feasibility of goat farming (Godber et al. 2020). A goat's ability to consume food effectively, withstand heat stress, and maintain healthy hooves, all of which are crucial in semiarid environments, is also influenced by genetic variables (Wanjala et al. 2023). Therefore, increasing total goat productivity in these arid areas requires a holistic approach that takes these genetic features into account along with management techniques, nutrition, and healthcare.

4.5. Housing systems for goats

Housing is an important component of goat production systems since it has a substantial impact on the productivity, welfare, and health of goats. Depending on variables such as operation size and intensity, different housing types, such as open kraals, walled and roofed shelters, and elevated floors with wooden walls, offer varying benefits and drawbacks. To maximize goat output, the choice of housing is important, particularly when considering the effects of climate change. Parwada et al. (2021) showed that 48% of Zimbabwean farmers kept their goats in open kraals, with many of them having enclosures with no flooring, and many of these farmers experienced high mortalities within their goat herds during winter.

This behaviour is frequently coupled with a lack of knowledge about the potential advantages of appropriate shelters, which can lower death rates, particularly for young goats, and prevent a variety of diseases. Furthermore, a few farmers still do not know that low-cost local materials can be used to build goat houses. On the other hand, farmers who are more knowledgeable about goat husbandry choose taller, thatched kraals since they are known to be suitable for giving goats a suitable place to live (Kahumba and Tefera 2023). These shelters boost goat welfare and productivity while protecting against severe weather, particularly in semiarid areas where the consequences of climate change are becoming more noticeable. Encouraging goat farmers to understand the value of adequate housing and offering advice on low-cost building techniques that make use of locally accessible resources is essential for reducing the negative effects of climate change on goat productivity and guaranteeing the general health of goat herds.

4.6. Land use and grazing management

Goat productivity must be maximized through efficient land and grazing management techniques, especially in semiarid areas where goats do well on marginal soils. Even if they can adapt to these kinds of situations, it is still imperative to implement management techniques that support healthy land and grazing practices, particularly in light of how climate change is enforcing environmental changes. According to research by Simpkin et al. (2020), goats can survive on marginal terrain that is not suitable for growing crops. However, goat farmers need to prioritize sustainable land use techniques and adjust to new problems as the environment changes, including changes in temperature and precipitation patterns. Grazing has a substantial impact on forest density and carbon storage; Wang et al. (2022) identified grazing as the principal land use in semiarid regions worldwide.

To preserve soil health, improve carbon sequestration, and guarantee sustainable land use in the face of climate change, farmers must carefully manage the division and rotation of grazing pastures. Climate change exacerbates the effects of poor grazing land management, which can result in nutrient deficits, soil erosion, and biodiversity loss. In addition to harming goat health and reproduction, these variables also decrease the resilience of ecosystems and degrade the environment. On the other hand, goat herd resilience and productivity can be increased by implementing good land management techniques, including rotational grazing, replanting of degraded areas, and soil conservation measures. Furthermore, by protecting natural habitats, improving carbon sequestration, and fostering ecosystem health, these actions help to lessen the effects of climate change (Wang et al. 2022).

5. Climate change mitigation strategies

5.1. Nutritional strategies

Climate change threatens goat production in semiarid areas by reducing forage availability and water scarcity. However, effective nutritional strategies can be implemented to

Table 1. High-yielding forage grass species adapted to semiarid environments.

Species Type	Scientific Name	Common Name	Characteristics	Yield per Hectare (approx.)	Soil and Climatic Requirements
Perennial	*Panicum maximum*	Guinea Grass	High palatability High yield. Nutrient-rich. Suitable for cutting and grazing. Adapted to various soils	18–25 tons	Grows best in fertile humus-rich loam soils Well-drained soils Rainfall over 1100 mm
Perennial	*Brachiaria decumbens*	Signal Grass	Rapid growth. Tolerant to grazing. High palatability. Good drought resistance	15–20 tons	Wide range of soils. Can also survive low fertile soils. Sensitive to saline.
Perennial	*Chloris gayana*	Rhodes Grass	Robust and adaptable. High yield. Suitable for hay production and grazing. Good palatability.	15–20 tons	Performs best on light and medium-textured soils Well-drained soils Warm temperatures
Perennial	*Cenchrus ciliaris*	Buffel Grass	Excellent drought tolerance Deep-rooted Suitable for arid regions Moderate palatability	12–18 tons	Wide range of soils, well-drained. Moderately tolerant to salinity 300 mm to 750 mm rainfall
Perennial	*Eragrostis superba*	Flat seed love grass	Hardy tufted. Highly palatable (winter). Arid and semiarid regions	13.5–15 tons	Sand and gravel soils
Perennial	*Setaria anceps*	Golden Timothy	Easy establishment. Good palatability. Robust plant. Leafy and good quality forage	Dryland 10–15 tons, Irrigated and fertilized 26–28 tons	Usually, on clay soils and rocky hillsides. Does better at 18–20 degrees Celsius
Annual	*Setaria palide-fusca*	Foxtail	Quick growth. Cannot withstand heavy grazing. Leafy and tufted. Good palatability.	15–20 tons	Frost-sensitive Wide range of soils but not on alkaline soils 00–700 mm of rainfall
Annual	*Digitaria eriantha*	Pangola Grass	Quick establishment Good regrowth potential Ideal for intensive grazing Good palatability	10–15 tons	Warm and moist environments – 450 mm to 750 mm rainfall Light and well-drained soils
Perennial	*Urochloa mosambicensis*	Gonya Grass	Highly palatable Vigorous growth. Quick establishment. Drought tolerant	Varies with rainfall: 1–8 tons	Wide range of soils with good drainage. Can grow in nutritionally poor soils.
Perennial	*Themeda triandra*	Rooi Grass	Highly palatable Natural savanna. Low yield compared to other grasses e.g. Rhodes Grass	0.5–5 tons	Prefers soils with high organic matter. Moderate to high rainfall Well-drained soils

Source: Gibson (2009), BioVision (2023) and Zimbabwe Flora (2023).

improve goat productivity and build resilience against these challenges. One key approach is rotational grazing, which prevents overgrazing and encourages the regrowth of drought-tolerant forage species such as Buffalo grass, Napier grass, and spineless Cactus (Ibrahim and Usman 2021). This practice conserves existing resources and helps grazing lands adapt to changing climates.

Furthermore, identifying and promoting drought-resistant forages provides a more reliable food source during dry periods (Table 1). This reduces the dependence on rain-fed forage and mitigates the effects of droughts (Makkar et al. 2022). Integrating forage tree species such as *Vachellia, Calliandra, Acacia*, Moringa, and *Leucaena* into grazing systems offers another valuable source of high-quality fodder, especially during dry seasons (Makkar et al. 2022). These trees, which are grown as windbreaks, hedges, or alley crops, also improve soil fertility, organic matter content, and water retention (Nair et al. 2021). Targeted supplements can address vitamin deficiencies and compensate for nutritional gaps in available forage. The specific type and amount depend on the forage quality and physiological stage of the goats (e.g. maintenance, pregnancy, lactation) (Luginbuhl 2015; Hart and Smith 2023).

Techniques such as haymaking, silage production, and crop residue utilization can ensure a year-round supply of feed, even during droughts or periods of limited forage availability (Mugoti et al. 2023). This helps buffer the effects of climate variability on goat nutrition. Finally, selective breeding programmes can improve genetic characteristics related to forage utilization and nutrient efficiency. This can lead to improved productivity even under challenging dietary conditions caused by climate change (Moyo et al. 2023).

5.2. Climate smart feeding systems

The choice of feeding system hinges on several factors, including herd size, the amount of available grazing land, and climatic conditions. An extensive feeding system is ideal for large herds with access to vast natural pastures in arid and semiarid regions (Kahumba and Tefera 2023). However, careful climate-smart management practices are needed. Implementing rotational grazing prevents overgrazing and allows for the regrowth of drought-resistant forage species, leading to improved pasture health and reduced land degradation. During dry seasons or periods of limited forage availability, strategic supplementation with locally available, drought-resistant options such as tree legumes (Singh 2023) or browsing plants is crucial to meet the nutritional needs of goats. Additionally, ensuring adequate access to clean water throughout the grazing area is essential for goat health and productivity, with strategically placed watering points minimizing overgrazing around water sources (Sejian et al. 2021).

The tethering system is suitable for smaller herds, particularly in areas with limited grazing land (Kahumba and Tefera 2023). However, close attention should be given to preventing negative impacts such as the death of animals and land degradation. To be climate smart, tethering areas need regular rotation to prevent soil compaction and overgrazing. The use of drought-resistant forage species within the tethering area is essential. Providing tethered goats with fresh, high-quality forage cut from drought-resistant browning plants or cultivated forage plots is crucial (Devendra and McLeroy

1982). Limiting tethering time during peak sun hours helps minimize heat stress, a growing concern due to climate change (Kumar et al. 2018).

The semi-intensive feeding system, a balanced approach, is ideal for medium-sized herds and integrates both free-range grazing and stall feeding (Kahumba and Tefera 2023). Climate-smart adaptations include developing pastures with a mix of grasses, legumes, and drought-resistant forage species. The use of drought-tolerant perennial grasses reduces the need for frequent reseeding, minimizing environmental impacts. Creating a forage bank by making hay or silage during periods of surplus forage growth provides a valuable feed source during dry seasons or droughts, buffering against the effects of climate variability (Mugoti et al. 2023). Targeted supplementation with locally available resources such as crop residues or byproducts can address any remaining nutritional gaps in the available forage, ensuring optimal goat health and productivity (Chisoro et al. 2023).

While intensive feeding systems offer greater control over goat nutrition, their applicability in semiarid regions is limited due to the high dependence on purchased feeds and water resources. They may be more suitable in peri-urban areas with access to markets and resources. If implemented, prioritizing feed efficiency with options that are highly digestible and have a low environmental impact is crucial. Exploring locally produced and climate-resilient feed ingredients can further enhance sustainability (Ronco and Ayadi 2023; Ndudzo et al. 2023). Minimizing feed waste through proper feeding practices and monitoring feed intake is essential for both economic and environmental reasons (Empel et al. 2016).

The Cut and Carry System involves cultivating fodder and transporting it to animals, seamlessly integrating it with any grazing system, and proving particularly valuable in areas with limited grazing land (Kahumba and Tefera 2023). To be climate-smart, cultivating drought-resistant forage crops such as legumes or browse plants provides a reliable source of cut-and-carry fodder, reducing the dependence on rain-fed forage (Singh 2023). Implementing water-efficient irrigation practices for cultivated forage crops is essential in water-scarce regions. Furthermore, drawing inspiration from successful initiatives such as the cultivation of important trees in South Africa, albeit primarily for medicinal purposes, offers a practical example of how similar approaches could be applied to forage crops (Van Wyk and Prinsloo 2018). By harnessing the benefits of agroforestry and integrating key tree species into the landscape, farmers can enhance resilience to climate change while simultaneously providing valuable fodder resources for livestock. The incorporation of rainwater harvesting techniques in conjunction with these practices can further reduce the reliance on freshwater sources (Dile et al. 2013). Table 2 details the nutritional needs, climate-smart feed provisions, and challenges for goats in semiarid ecosystems.

5.3. Health and disease management

Managing health and disease is of the utmost importance for goat husbandry. To protect the welfare of the goat herd, given the tough and frequently unpredictable conditions, which include severe temperatures and scarce resources, a specific strategy is needed. The prevention of sickness is the initial stage of this procedure. Singh (2023) suggested a strict biosecurity strategy to reduce the danger of disease transmission, which entails

Table 2. Nutritional needs, climate-smart feed provisions, and challenges for goats in semiarid ecosystems.

Production Stage	Grain in Roughage Diet (%)	Nutritional Needs	Climate-Smart Feed Options	Challenges	Source
Maintenance	0–10 (Goats)	Low energy, moderate protein, high fibre	Browse available shrubs and trees (e.g. vachellia/acacia, mesquite) - a renewable resource	Seasonal availability	Stavi et al. (2023)
			Legume hay (e.g. alfalfa) - improves soil nitrogen		Dhakal and Islam (2018)
			Cactus pads (chopped and deseeded) - drought-tolerant forage	Processing required	
Late Pregnancy	10–20 (Goats), 15–25 (Meat Goats)	Increased energy, moderate protein	Browse supplemented with protein-rich pulses (e.g. chickpeas, lentils) - nitrogen-fixing crops	May require additional land for cultivation	Timpong-Jones et al. (2023)
			Seed pods from drought-resistant legumes (e.g. guar)	Seasonal availability	Vishnyakova et al. (2023)
			Grain byproducts (e.g. brewers' grains) - reduce food waste	Storage and transportation needs	Romero-Huelva et al. (2017)
Early Lactation	20–30 (Goats), 25–40 (Meat Goats)	High energy, high protein	High-quality browse supplemented with moringa leaves - fast-growing, drought-resistant, high-protein forage	Requires initial investment in establishing moringa trees	Korsor (2018)
			Silvopasture system (integrating trees with forage) - provides shade and improves soil moisture	Long-term planning and management needed	Nair et al. (2021)
			Fodder beets or turnips - drought-tolerant root vegetables	Requires sufficient water for successful cultivation	Benedict et al. (2013)
Late Lactation	10–20 (Goats), 15–25 (Meat Goats)	Moderate energy, moderate protein	Gradually reduce grain while maintaining browse and protein sources		Devendra and Leng (2011)
			Fermented cactus pads (improve digestibility)	Processing and storage requirements	Morshedy et al. (2020)
			Crop residues (e.g. corn stalks) - utilize agricultural waste	May require additional processing for palatability	(Kamusoko et al. 2021)

quarantining new animals and maintaining strict hygiene standards. Disease prevention relies heavily on a well-organized vaccination and deworming programme created in conjunction with a veterinarian (Singh 2023). The timetable must be adjusted to coincide with the local epidemics of diseases to safeguard the herd from frequent maladies. Additionally, it is crucial to feed goats a well-balanced diet that meets their particular nutritional requirements. In addition to improving the overall health of the animals, proper feeding also strengthens their immune system and increases their disease

Table 3. Mitigation of climate change-related diseases.

Common Diseases	Climate Change Effect	Impact on Goats	Proposed Climate-Smart Mitigation Strategies	Source
Vector-borne diseases (e.g. heartwater, bluetongue)	Increased temperature and humidity; changes in rainfall patterns	Increased tick and mosquito populations that transmit diseases	Improved animal housing with good ventilation and insect control measures. Strategic use of acaricides and insecticides based on vet recommendations (e.g. rotational usage). Vaccination programs for prevalent diseases.	Rodolakis (2014) Perveen et al. (2021)
Parasitic diseases (e.g. gastrointestinal nematodes)	Warmer temperatures; and increased moisture promote parasite survival	Increased parasite burdens lead to weight loss, diarrhea, and reduced productivity.	Rotational grazing to break parasite life cycles. - Strategic deworming based on fecal analysis. Utilizing browsing plants with natural anthelmintic properties (consult a veterinarian).	Fthenakis and Papadopoulos (2018). Rizwan et al. (2023).
Heat stress	Rising temperatures; reduced water availability	Reduced feed intake, decreased milk production, increased respiratory rate, lethargy.	Providing ample shade and cool drinking water throughout the day. Selecting heat-tolerant breeds and avoiding strenuous activity during peak heat hours. Improving ventilation in housing.	Sejian et al. (2021) Joy et al. (2020)
Pneumonia	Dust storms associated with increased drought and erratic rainfall can irritate respiratory systems.	Difficulty breathing, coughing, weight loss, increased susceptibility to secondary infections.	Implementing windbreaks and shelterbelts to reduce dust exposure. Providing good quality forage to maintain a strong immune system.	Joseph (1979) Turkar and Devi (2024).
Nutritional deficiencies	Droughts and erratic rainfall patterns can impact forage quality and availability.	Reduced milk production, weakened immune system, decreased fertility.	Utilizing drought-resistant forage species in pastures. Exploring options for on-farm feed production using drought-tolerant crops. Implementing supplementary feeding strategies with locally available resources like browse, cactus pads, or crop residues.	Ali et al. (2019). Simões et al. (2021).

resistance. Supplements or better forage management should be used to treat any nutrient shortages as soon as possible (Yadav et al. 2020).

To avoid dehydration, which can increase the susceptibility of goats to disease, it is essential to ensure that they have access to enough water (Sejian et al. 2021). In semiarid environments, heat stress is a major concern for goats. To help them cope with heat, cooling spaces, shaded places, and misting systems should be implemented (Gupta and Mondal 2021). Maintaining thorough health records is crucial for effective goat management. This allows for easy tracking of immunizations, deworming, and disease episodes, which are vital for early detection and management of health problems. Additional factors to take into account to avoid lameness, a condition that can worsen in semiarid areas, include footing and hoof care (Temple and Manteca 2020). The overall health of the herd can be improved over time by selectively breeding for disease resistance and tolerance to the difficulties of semiarid environments (Moyo et al. 2023). It is crucial to have a plan for disease outbreaks that involves separating afflicted animals and calling for veterinary help. Table 3 highlights the common climate change-related diseases and the proposed mitigation strategies.

5.4. Livelihood, socioeconomic and cultural factors

Socioeconomic and cultural factors are pivotal in shaping the sustainability of goat production systems, particularly in the face of climate change. Local knowledge and traditional practices serve as valuable resources, offering insights into effective management strategies amidst shifting environmental conditions (Phiri et al. 2020). Community participation and support are instrumental in promoting sustainable practices, fostering resilience, and adapting to the impacts of climate change. Improved market access and value addition to goat products not only offer economic incentives for farmers but also contribute to climate resilience. By enhancing market opportunities, farmers are encouraged to adopt sustainable goat production methods that align with climate-smart principles (Nguyen et al. 2023).

Livelihood diversification and resilience strategies, such as economic uncertainty and environmental stressors, are indispensable for communities confronting various challenges exacerbated by climate change. Agricultural diversification, encompassing the cultivation of diverse crops and the rearing of different animal species, serves as a cornerstone for building resilience against fluctuating market demand and climatic variability (Stringer et al. 2020). Additionally, non-agricultural revenue streams, including small enterprises, services, and off-farm job options, play a vital role in enhancing community resilience and reducing vulnerability (Ngambi et al. 2013). Adopting climate-resilient farming techniques, such as water harvesting and the cultivation of drought-resistant crop varieties, safeguards agricultural livelihoods from the unpredictability of shifting weather patterns (Srivastav et al. 2021). Furthermore, market diversification and value addition in supply chains provide farmers and producers with additional revenue streams, enhancing their adaptive capacity in the face of climate change.

A strong emphasis on natural resource management, sustainable livelihood diversification, and disaster preparedness significantly enhances community resilience (Uddin et al. 2021). These strategies empower individuals and communities to respond adeptly to challenges, seize new opportunities, and foster social cohesion through strengthened community networks, capacity building in leadership and entrepreneurship, and the promotion of gender equality and social inclusion.

5.5. Goat breeds and genetic selection strategies

Genetic selection has emerged as a crucial factor in enhancing productivity and sustainability within goat production systems, particularly in light of climate change. Selective breeding aimed at developing resistance to diseases, drought, and heat stress holds promise for cultivating more resilient goat breeds. The Boer goat stands out as one of the most prevalent breeds in semiarid regions, originating from South Africa and widely introduced to various countries globally (Chawatama et al. 2020; Weaver 2021). Boer goats exhibit high growth rates, superior meat quality, and remarkable adaptability to diverse environmental conditions. However, the initial investment required to purchase Boer goats may pose a challenge for many smallholder farmers due to their high market value (Marius et al. 2021). To overcome this barrier and promote sustainable goat production within communities, the introduction of communal goat production cooperatives could be explored. In such cooperatives, communities collectively invest in purchasing a single buck for breeding purposes. This buck can then be mated with locally available female breeds, gradually increasing the size of the local goat population. By pooling resources and sharing the costs associated with acquiring high-quality breeding stock, smallholder farmers can enhance their capacity for goat rearing while benefiting

Table 4. Characteristics of goat breeds in semiarid regions.

Breed Name	Characteristics	Adaptability	Background Information	Source
Boer	Fast growing, large size, muscular build, short hair, reddish-brown coat	High	Originated in South Africa, known for meat production.	Dzama et al. (2013); Rout et al. (2021); Weaver (2021)
Spanish	Hardy, adaptable, good meat yield, long, twisted horns	High	Also known as "Spanish Meat Goat", raised for meat.	Romanov et al. (2021); Weaver (2021)
Nubian	Large size, long ears, high milk yield, gentle personality	Moderate	Known for both milk and meat production and gentle temperament.	Rouatbi et al. (2022); Weaver (2021)
Kiko	Hardy, disease-resistant, fast-growing, good meat yield	High	Developed in New Zealand for meat production and disease resistance.	Parajuli (2020); Ramoroka (2020)
Myotonic	Muscular build, stiffening of muscles when excited, good meat yield	Moderate	Also called "Fainting Goat", primarily raised for meat.	Weaver (2021)
Boer cross	Excellent meat yield. However, characteristics depend on the other breed used	Moderate-High	Crossbreeding can inherit traits from Boer and the other breed.	Manirakiza et al. (2020); Gama et al. (2020)
Mashona	The Indigenous Zimbabwean breed is known for its adaptability to local environmental conditions, resistance to common diseases, and moderate meat yield.	High	Known for adaptability to arid conditions.	Moyo et al. (2023); Kajevhu and Mabika (2023)
Matabele	Ability to thrive in semiarid regions, and suitability for meat production under extensive farming systems.	High	Adapted to semiarid environments.	Moyo et al. (2023); Kunaka et al. (2023)
Red Kalahari	Developed in South Africa, good meat yield, and a reddish coat.	High	Known for meat production, suited for arid conditions.	Tyasi and Tada (2023)
Black Bengal	Black coat, medium size, good milk yield	Moderate	Adapted to hot and humid climates	Kumar et al. (2018); Singh (2023)
Sirohi	White coat with black markings, medium size, good milk yield	Moderate	Known for hardiness and disease resistance	Singh (2023); Kumar et al. (2018)
Beetal	White or light brown coat, medium size, good milk yield	Moderate	Adapted to diverse climates and terrains	Ramzan et al. (2020)
Toggenburg	Brown and white coat, medium size, and good milk yield	Moderate	Originated in Switzerland, known for hardiness and good milk production	Haenlein (2007); Campbell (2003); Kauta (2009)

from the desirable traits of Boer genetics. Additionally, communal cooperatives foster knowledge-sharing and collaboration among farmers, further strengthening the resilience of the local goat farming sector (Dzama et al. 2013; Gupta and Mondal 2021).

Another notable breed in semiarid regions is the Spanish or brush goat, distinguished by its hardiness and ability to subsist on sparse vegetation in rugged terrains (Gipson et al. 2019). Spanish goats exhibit versatility, excelling in meat, milk, and fibre production, and are recognized for their reproductive ability and high twinning rates, making them invaluable for augmenting herd size (Gipson et al. 2019). Their adept foraging abilities enable them to consume tough weeds, shrubs, and even cacti, contributing to ecosystem resilience in regions where other goats may struggle (Gipson et al. 2019). Table 4 shows some of the goat breeds adapted to semiarid environments.

Nubian goats are also common in semiarid regions due to their heat tolerance, superior milk production, and adaptability to arid environments (Kosgey et al. 2014). They have long, pendulous ears that help dissipate heat and maintain body temperature. Nubian goats are excellent for dairy production, and their milk is high in butterfat and protein (Kosgey et al. 2014). In addition, they are easy to handle and can serve as pack animals in rocky terrain (Kosgey et al. 2014). In some semiarid regions, indigenous goat breeds exist, such as the Small East African goat and the Sokoto Gudali (Mwacharo et al. 2017). These breeds have evolved over a long time to adapt to local environments and meet the needs of the communities that rear them (Mwacharo et al. 2017).

These breeds are strongly resistant to diseases, pests, and parasites and can survive on low-quality forages (Mwacharo et al. 2017). Indigenous goats are typically smaller than exotic breeds but are valued for their hardiness, reproductive efficiency, and cultural significance (Mwacharo et al. 2017). Goat breeds in semiarid regions must possess certain traits, such as heat tolerance, adaptive abilities, and foraging skills. The Boer goat, Spanish goat, Nubian goat, and indigenous goat breeds are some of the breeds that have been developed or adapted for these regions.

5.6. *Climate smart housing systems*

For housing systems, providing goats with optimal shelters is essential for minimizing the negative impact of climate change (Table 5). The goat house should provide an optimal environment for growth and protection from disease and stress. The requirements for good goat housing are as follows: the floor of the house must be elevated; floors can be made of wood, sand, or concrete; and the walls must be well-ventilated and have access to sunlight, especially during winter (Thonney et al. 2022). The housing must have a 2% slope towards the drainage area since goats need dry environments. Housing must have a roof to protect goats from direct sunlight, rainfall, and cold weather. The housing must not be muddy or waterlogged since these conditions cause foot rot. Feed and water troughs should be kept off from the ground to prevent them from being tramped, and they should be kept at a height that kids can reach (Samala 2021).

In walled and roofed housing, the walls are well-ventilated and warm and protect goats from wetness during rainy seasons; the surfaces are easy to clean, and the roofing is performed with asbestos, iron sheets, or thatching grass. In steel bars or fences and roof housing, roofing is performed with asbestos or iron sheets. Fences help protect goats from rain and high temperatures (Sejian et al. 2021). Another disadvantage is that the

Table 5. Optimal goat housing requirements in semiarid regions.

Aspect	Description	Benefits	Considerations	Source
Location	Well-drained area with good air circulation, avoiding low-lying areas or those prone to flooding. Consider prevailing winds and sun exposure for optimal comfort.	Minimizes moisture buildup and risk of disease. Provides protection from harsh weather conditions.	Assess land topography and drainage patterns. Consider local wind patterns and sun exposure.	Sivakumar et al. (2005) Westmacott and Blandford (2021)
Shelter Design	Materials: Locally available, durable, weather-resistant materials (e.g. wood, bricks, stabilized mud blocks). Ventilation: Adequate ventilation through roof vents or strategically placed openings. Roofing: Sloped roof with overhang for shade and drainage (metal, thatch, or insulating materials depending on climate). Flooring: Raised (at least 30 cm) for drainage, with concrete or compacted earth floors and adequate bedding.	Protects goats from extreme temperatures, rain, wind, and predators. Ensures good air circulation and reduces moisture buildup. Provides shade and drainage.	Durability and weather resistance of materials. Balance ventilation needs with protection from wind and drafts. Heat reflection during hot weather (metal roofs). Comfort and insulation for goats (bedding).	Sejian et al. (2015) Ambazamkandi et al. (2015)
Space Requirements	Minimum: 3–4 square meters (32–43 square feet) per adult goat. Adjustments: Kids (up to 3 months): 1–2 square meters (11–21 square feet). Growing Kids (3–6 months): 2–3 square meters (21–32 square feet).	Provides adequate space for movement, comfort, and social interaction. Ensures proper growth and development.	Consider breed size and age when allocating space.	Andersen and Bøe (2007)
Additional Space Needs	Kidding Areas: Separate, well-bedded pens for birthing does. Breeding Groups: Dedicated space for bucks and breeding does (if separated). Sick Bay: Isolated area for sick or injured animals.	Ensures a clean and safe environment for mothers and newborns. Prevents unwanted breeding outside designated areas. Minimizes disease transmission within the herd.	Allocate sufficient space for birthing behaviour and newborn care. Consider group dynamics and breeding practices. Provide a quiet and stress-free environment for sick animals.	Andersen and Bøe (2007) Sharma et al. (2024)
Other Considerations	Feeders and Waterers: Easy access to clean water and good quality feed. Bedding: Deep layer of comfortable and absorbent material (straw, wood shavings). Fencing: Strong, predator-proof fencing around the perimeter. Natural Light and Ventilation: Allow for natural light and adequate ventilation.	Ensures good health and productivity. Provides comfort and hygiene. Protects goats from predators. Maintains air quality and prevents moisture buildup.	Design feeders and waterers to minimize waste and contamination. Regularly replace soiled bedding. Height and strength of fencing appropriate for local predators. Avoid drafts while maintaining air circulation.	Sharma et al. (2024)

animals are affected by high winds. Curtains can be used in winter to prevent cold. With a raised floor with wooden walls, roofing, and a feeding area, this housing allows goats to be fed at the pens. The house is easy to clean, and the floors are well drained, which reduces foot rot disease. The floors are elevated to 60 cm, and the distance between the layers is 2 cm. With Poles and a roof with no floors, this housing allows free circulation of air since it is well ventilated (Zobel and Nawroth 2020). It is cheap to build. The disadvantage of this housing is that it exposes the goats to harsh conditions such as heat, cold, and rain. When the floors become wet, foot rot affects the animals. The housing for kids is warm and dry, which suits the conditions required by kids during their first four weeks of life. The housing protects kids from heat, rain, and cold.

Well-ventilated structures with access to sunlight, elevated floors, and protection from harsh weather conditions are fundamental for ensuring the health and well-being of goats (Sejian et al. 2021). Various housing types, from walled and roofed structures to raised floors and kid housing, offer flexibility to meet diverse needs caused by the ever-changing local climate.

5.7. Land use and grazing management

Land use and grazing management are critical factors that can impact the productivity and sustainability of goat production systems in semiarid regions. By implementing sustainable grazing practices such as rotational grazing, integrating forage crops, and utilizing water resources more efficiently, farmers can maximize their yields while minimizing negative impacts on the environment (Balasundram et al. 2023). Overgrazing or incorrect allocation of grazing lands can lead to land degradation and reduced forage quality (Ibrahim and Usman 2021). Implementing a rotational grazing system is essential to provide proper rest and recovery periods for the land. This involves dividing the grazing area into smaller paddocks and rotating the goats through them, allowing the land to recover and regenerate before the goats return to graze again (Köhler-Rollefson 2023).

Rotational grazing also helps to distribute manure more evenly across the land, which can improve soil fertility and reduce the risk of nutrient runoff (Teague and Kreuter 2020). Integrating forage crops into the grazing system further improves soil health and increases forage quality. Forage crops such as alfalfa, clover, and ryegrass provide additional nutrition for goats while also improving soil structure and fertility (Chand et al. 2022). These crops can be grown in rotation with grazing areas or in separate fields used for hay production, contributing to long-term forage availability (Hart *et al.*, 2023). The efficient utilization of water resources is crucial, particularly in semiarid regions where water scarcity is a challenge. Implementing irrigation systems or rainwater harvesting techniques can ensure that goats have access to adequate water supplies even during dry periods. By using water more efficiently, farmers can maintain the health and productivity of their goats, especially during drought conditions. Therefore, farmers and policy-makers must prioritize the implementation of sustainable grazing practices along with appropriate land use and water management strategies to ensure the long-term viability of goat production systems.

6. Conclusion and recommendations

Goat farming in semiarid environments is a dynamic endeavour with opportunities and problems. Goat farming faces significant challenges in these areas due to limited feed availability, unpredictable weather patterns, and scarce water resources. In particular, water scarcity can be an urgent issue that calls for creative approaches to water management to protect goat welfare. Adaptive techniques are necessary for sustained production because climate unpredictability, which is typified by droughts and extremely high temperatures, can interfere with feeding schedules and reproductive rates. In semiarid regions, illness risk is also a major concern; thus, proactive management and attentive observation are required to protect goat health. These difficulties are exacerbated by limited market access since these rural areas frequently provide transportation and marketing obstacles.

Nonetheless, these difficulties present incredible opportunities for individuals involved in the production of semiarid goats. Productivity and disease resistance can be increased by choosing and producing resilient goat breeds that are suited to these environments. Forage shortages can be lessened by diversifying farming techniques such as agroforestry and intercropping, and steady water supplies can be ensured by effective water management techniques such as rainwater collection. Additionally, adding value to goat products can boost the profitability of goat farming by generating new revenue sources. In addition to community cooperation and climate-resilient practices, education and training programmes that give farmers fundamental knowledge and abilities for managing goats sustainably are necessary. Policies that address goat productivity are necessary for a business to succeed and to guarantee farmers' support. When combined, these chances provide a means to produce goats in semiarid areas in a more resilient and sustainable manner, protecting the livelihoods of individuals who rely on these priceless animal resources. To lessen these consequences, climate-resilient practices must be implemented. These practices include improved management of feed and water, the provision of shade and appropriate housing, disease control techniques, and selective breeding for disease resistance and heat tolerance. By adopting the suggested interventions, it will be simpler to maintain the sustainability and viability of goat farming in semiarid regions, safeguarding the livelihoods of those who depend on this significant sector. International cooperation is essential for solving these problems, exchanging knowledge, and developing solutions that benefit everyone because climate change is a transboundary phenomenon.

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Data sharing is not applicable to this article as no new data were created or analysed in this study.

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