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Resilient livestock and poultry production for a sustainable food system

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ABSTRACT

To achieve a sustainable global food system in the face of climate change, environmental degradation, and population development, this study delves into the concept of resilient livestock and poultry production. The literature stresses the need for resilience in livestock systems, which is marked by strength, flexibility, and the capacity to transform, to survive and thrive through economic and climate challenges. Various researches on biosecurity, sustainable feeding, genetic enhancement, technology innovation, and policy support have been gathered and examined in this research. The findings indicate that the performance of animals is seriously impacted by heatwaves, drought, and pandemics. But with adaptive approaches such as genetic improvement, sustainable waste management, and precision livestock farming, these issues can be mitigated. Apart from reducing the emission of greenhouse gases and improving nutritional security, a circular bioeconomy that leverages digital technology enhances resource use efficiency. To build resilience, support from institutions and policies is necessary, particularly through inclusive governance and economic rewards. Resilient livestock systems are vital to sustainable agriculture and climate-resilient living because they enhance food and nutritional security, economic stability, and environmental sustainability.

Introduction

Strong livestock and poultry systems are vital for food security and sustainable agriculture worldwide. Climate change, population growth, and environmental harm present unprecedented threats. These systems must withstand shocks, adapt to new situations, and reinvent themselves as needed to maintain food supply and support rural livelihoods. Livestock and poultry resilience go beyond mere survival or overcoming shocks. It involves the connections between socio-ecological systems, including the animals, the people who depend on them, and their environments. These systems should be able to absorb disturbances, adjust to changes, and transform without losing essential processes. Even when normal life is disrupted, strong animals can endure disturbances and soon return to normal functioning. This definition includes three key abilities. The first is robustness, which refers to the ability of animals and systems to keep production levels up in various environmental conditions. The second, adaptive capacity, involves learning, innovation, and flexible management practices that allow systems to adjust to changes. The third, transformative capacity recognizes that sometimes the basic framework must be rearranged.

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This could mean changing livestock species, adopting new production systems, or diversifying livelihoods. In the long run, the frameworks need restructuring (Laghouaouta et al., 2024). The resilience crisis in livestock and poultry systems results from intersecting pressures that threaten the sustainability and productivity of these crucial industries. Rising temperatures, heat waves, unpredictable rainfall, extended droughts, and extreme weather significantly affect livestock and poultry production globally (Bashiru and Oseni, 2025). Climate change poses multiple threats to livestock systems, including heat stress, which reduces feed consumption and egg quality; changes in disease distributions, which expand the range of disease vectors; water scarcity, which limits drinking water and irrigation for feed crops; and variations in temperature and precipitation that impact crop production, affecting feed supplies and their nutritional value (Godde et al., 2021; Oke et al., 2024). Global warming is predicted to increase stressful days as early as 2100, significantly impacting livestock production, especially in developing areas where climate variability and limited adaptive capacity coexist. Poultry production faces specific challenges: when temperatures exceed 41°C, egg production can drop by up to 60%, and meat production can decrease by up to 55% in affected regions (Osuji et al., 2024; Singh and Ukey, 2024; Bashiru and Oseni, 2025). Today, livestock farming accounts for 40 percent of overall agricultural output. Animal products provide one-fifth of the world's diet and 31 percent of global protein, with significant regional variation. Approximately 30 percent of ruminant meat and milk is produced in grazing systems that do not involve cropping. By 2050, the global population is projected to reach 9 billion, a 30 percent increase, requiring a 70 percent boost in production. The demand for meat is expected to rise by 73 percent and for milk by 58 percent by 2050 (Godde et al., 2021; Ederer et al., 2023; Pampori and Sheikh, 2023). Over 60 billion land animals are raised annually to provide food for the world's population. By 2050, the number of livestock is expected to double, with most growth occurring in developing countries. This increasing demand strains already fragile production systems, which are further challenged by climate variability and limited resources (Bashiru and Oseni, 2025). Critics point to the environmental impact of the livestock industry. It contributes about 14.5 percent of global greenhouse gas emissions, mainly through methane from ruminants. Pastureland and feed crop cultivation often result in deforestation, reducing carbon sinks. Other concerns include water pollution from nutrient-rich runoff, land use changes leading to erosion, loss of biodiversity from habitat destruction, and increasing antimicrobial resistance due to excessive antibiotic use (Nayak, 2024; Singh et al., 2025). Livestock farming faces economic challenges due to fluctuating input and output prices, high feed costs, limited access to credit, and market volatility. These issues are worsened by poor infrastructure, inaccessible markets, inadequate biosecurity, and a lack of data for decision-making in low- and middle-income countries. The COVID-19 crisis exposed vulnerabilities in supply chains, particularly in developing nations that rely on imported food, vaccines, and medicines, leading to distribution disruptions and reduced production (Nassar and Abbas, 2025; Osuji et al., 2024).

Significance of Resilient Systems

Livelihood Protection

Animal agriculture provides a vital source of income for millions of vulnerable people living in communities that rely on livestock, especially in low- and middle-income countries (Bangert and Wheeler 2025). Livestock offer families income through product sales, food for nutrition, help with farming, and fertilizer for the soil (Stephen and Parmley 2022). Stable livestock systems protect these income sources from shocks and stresses while also promoting access to economic, social, and natural resources (Bashiru and Oseni 2025).

Nutritional Security

Food from animals offers essential nutrients, like high-quality protein, vitamins, and minerals. This is especially important for children, pregnant women, and vulnerable groups. Reliable production systems make sure these nutritious foods remain accessible, even during environmental and economic challenges. This stability contributes to food security and nutrition (Idamokoro, 2023).

Economic Stability

Livestock production plays an important role in economic growth and reducing poverty. Lowering operating expenses through good resource management, providing high-quality markets for sustainable products, and diversifying income sources strengthen the economy at both the farm and community levels (Thefarminginsider 2025). Investing in climate-resilient livestock systems can promote climate-smart practices, improve animal welfare, enhance food safety, and cut greenhouse gas emissions in the value chains (Sargison, 2020; Fao 2025a).

Environmental Stewardship

Livestock systems can positively impact environmental sustainability when managed properly. Integrated crop-livestock systems improve soil health by adding organic matter. They enhance carbon sequestration through strategic grazing, support biodiversity by preserving habitats, and make resource use more efficient (Manono and Gichana 2025). Climate-resilient livestock practices reduce environmental footprints while maintaining or increasing productivity (Varijakshapanicker et al., 2019).

Public Health Protection

One Health connects animal, ecosystem, and human health. Zoonotic diseases can emerge and spread, but resilient livestock systems can prevent this (Pandey et al., 2024). These systems have high biosecurity, good disease surveillance, and responsible use of antimicrobials (Qian et al., 2022). Healthy livestock reduce disease, improve nutrition, and support livelihoods, contributing to healthier communities (Thumbi et al., 2015; (Whylivestockmatter, 2025).

Climate Change Impacts on Livestock and Poultry Productivity

The issues related to climate change reduce the productivity of livestock and poultry. These problems are connected. Heat stress, lower feed availability, water shortages, and changes in disease patterns all contribute to this. They lead to decreased growth, reproduction, and overall health in animals, which raises mortality rates.

Temperature Stress

Rising temperatures and frequent heat waves put livestock under thermal stress. As heat stress increases, feed efficiency drops by about 35 to 5 percent for every degree Celsius above a comfortable temperature (Degefu and Milkias 2024). This leads to greater water needs, changes in metabolism, weakened immune systems, and lower reproductive performance, as well as reduced milk, meat, and egg production (Sakuma, 2024). Animals experiencing heat stress breathe faster, develop metabolic disorders, and become more vulnerable to diseases, further lowering productivity (Sejian et al., 2016).

Feed Scarcity

Climate change negatively affects rangeland productivity. Changes in rainfall patterns cause droughts, while rising temperatures lead to an increase in plant lignin, which decreases digestib ility (Senda et al., 2020). Less rainfall means less forage biomass, leading to nutritional stress that slows growth, lowers body condition, reduces milk production, and affects reproduction (Tiruneh and Tegene, 2018).

Water limitations

Water shortages are worsened by increased evaporation and prolonged dry spells. Livestock rely on steady water sources, but climate variability threatens this stability (Kevin et al., 2022). Water stress limits feed intake and reduces weight gain, milk production, and overall productivity (Assan, 2022). To address these challenges, some regions have turned to rainwater harvesting and water ponds nearby (Degefu and Milkias 2024).

Disease dynamics

Changes in temperature can affect the distribution and survival of pathogens and vectors. Heat stress weakens immune responses, increasing infection risks and reducing vaccine effectiveness (Shagun, 2022). Many Rift Valley fever outbreaks and tick-borne diseases are linked to reduced rainfall and higher temperatures. These risks not only raise veterinary costs and mortality but also threaten food security, especially among small-scale farmers (Patel and Prajapati, 2025). Genetic and breeding methods aim to create livestock and poultry that can resist climate challenges, focusing on heat tolerance, disease resistance, and feed efficiency. Maintaining native breeds ensures genetic diversity and ecological suitability (Sakuma, 2024).

Adaptation characteristics and thermoregulation

Breeding efforts focus on animals that can maintain production levels during heat stress. Modern techniques, such as marker-assisted selection (MAS), genomic selection (GS), and omics, identify genes and markers linked to heat resilience (Xiong et al., 2025; Shashank et al., 2024). Combining genomics, transcriptomics, and metabolomics helps reveal the molecular mechanisms behind heat responses (Juiputta et al., 2023). Current dairy and poultry programs are using these precise methods to enhance thermotolerance without sacrificing productivity (Juiputta et al., 2023).

Preservation of Native Breeds

Local breeds are often well adapted to heat, drought, and diseases, making them crucial for building resilience. Conserving and managing these breeds maintains a genetic pool that can offer valuable traits during climate change (Mahale, 2024). Breeds supported by policies and farming practices include Sahiwal, Red Sindhi cattle, and Banni buffalo. These breeds are not only heat-tolerant but also possess high productivity potential (Husbandry and Karnataka, 2016)

Choice of breeding and genetic strategies

The combination of traditional and genomic technologies speeds up the development of strong breeds. Strategies include:

- Crossbreeding adapted indigenous breeds with high-production breeds to balance resilience and yield (Stranden et al., 2019).
- Improving the selection accuracy of complex traits using genomic prediction models, such as GBLUP.
- Using genomic introgression to introduce adaptive alleles into productive populations (Arya et al., 2024).
- Creating breeding goals that focus on both production and resilience to help preserve diversity and reduce inbreeding (Koluman et al., 2025).

Integration to sustainable production

Genetic and breeding initiatives are part of broader resilience measures, including better nutrition, housing, disease management, and online welfare management (Taye et al., 2025; Priyashantha et al., 2025). When these methods work together, they can help maintain livestock productivity and decrease environmental impacts. This supports a sustainable food system (Koluman et al., 2025).

Genetic and breeding approaches

- Researchers are developing heat-tolerant, disease-resistant cattle breeds using genomic selection, marker-assisted selection (MAS), and genome editing technologies like CRISPR. This improves their capacity to adapt and produce under climate stress (Xiong et al., 2025).
- To maintain genetic variety and resilience, it is important to conserve and use native breeds that are suited to the climate (Taye et al., 2025).
- Multi-omics technologies and induced pluripotent stem cells are new tools that help us understand how animals adapt to heat stress and speed up genetic improvement (Taye et al., 2025).
- AI and IoT-enabled precision breeding allows for real-time monitoring and selection of climate resilience traits (Selvaraj et al., 2023).

Nutritional Techniques and Sustainable Feeding

Using a variety of fodders, like grasses and legumes, and climate-resilient forages can help maintain intestinal health, provide balanced nutrition, and reduce dependence on expensive concentrate feeds (Taye et al., 2025). Antioxidants and methane-reduction feed additives support performance during oxidative stress and heat while decreasing the environmental impact (Hayat et al., 2024). Organic acids and alternative feed sources improve intestinal health and reduce the pathogen load in chickens, which lowers the need for antibiotics (Development 2025). Better feed formulations and precision feeding systems improve feed sustainability and efficiency (Hayat et al., 2024). In integrated farming systems, sustainable feeding methods also promote nutrient cycling and soil health (Bhoyar, 2025).

Biosecurity, disease control, and animal health in a changing environment

Climate change significantly affects animal health through direct impacts like heat stress and reproductive issues, as well as indirect effects such as increased infectious diseases, vector-borne diseases, and parasites (Sharma et al., 2024). To reduce disease risks, we need strong biosecurity and biosafety measures, especially considering climate change and related disasters (Kiragu, 2023). To control disease risks, particularly zoonoses, the One Health approach is crucial. This approach connects environmental, animal, and human health (Dembe, 2024). It encourages teamwork across different fields and community involvement for better illness management (Hernandez et al., 2025; Gruetzmacher et al., 2021). While biosecurity practices differ worldwide, they are vital for managing health risks and preventing disease outbreaks in the dairy, poultry, and aquaculture sectors (Shukla and Bhattacharyya, 2025). We need to improve compliance with sustainable management and biosecurity measures, which can be supported by digital tools and targeted educational programs (Moje et al., 2023; Mwainge et al., 2024). Environmental changes, such as urbanization, shifts in land use, and climate variability, affect the emergence and spread of animal diseases (Windsor, 2024). These challenges are compounded by weaknesses in ecosystem health (Shukla and Bhattacharyya, 2025). This situation demands proactive biosecurity measures that consider climate adaptability (Wannous, 2020).

Policy framework and institutional support for resilient livestock systems

Technological innovations and digital tools are essential in strengthening livestock resilience through enhanced animal health monitoring, optimized resource utilization, and the implementation of precision management techniques, while sustainable waste management and circular bioeconomy principles support environmental sustainability and resource recycling within livestock systems.

Technological advancements and digital solutions for enhancing livestock resilience

Technological innovations like CRISPR genome editing are changing livestock production. They enable genetic improvements for disease resistance, heat tolerance, and productivity (Shaha et al., 2025). This change supports sustainable and resilient food systems. Precision livestock farming (PLF) uses sensors, wearable devices, Internet of Things (IoT) technology, and data analysis to monitor vital signs, animal behavior, and health. This monitoring helps in early disease detection and improves nutritional management (Kohila et al., 2024). Automated feeding systems and drones for monitoring pastures improve resource use and reduce waste. AI and machine learning analyze data to tackle heat stress, illness, and calving proactively. This approach enhances animal welfare and productivity (Bordignon et al., 2025). These advancements also help address climate change by increasing operational resilience and supporting climate-smart livestock management practices (Bordignon et al., 2025).

Sustainable waste management in livestock systems

Livestock waste management uses technologies like anaerobic digestion, composting, and biogas production to turn manure into renewable energy and nutrient-rich by-products. These systems reduce greenhouse gas emissions from manure, lessen odors, and create organic fertilizers and biogas for farming. Integrated systems manage livestock waste in a sustainable way (Trainingcred, 2025). They produce valuable by-products like struvite and high-quality effluent for agricultural reuse (Selakov, 2025). This supports the circular economy and lowers environmental impact (Sampat et al., 2018),

Circular bioeconomy within livestock systems

The circular bioeconomy in livestock agriculture focuses on closing nutrient cycles and optimizing the use of biomass that is unsuitable for human consumption, such as crop residues and byproducts from food processing. Livestock plays a vital role by converting and repurposing these materials into high-quality animal-derived products, organic fertilizers, and renewable energy sources (Openknowledge, 2025). This approach reduces competition for arable land, improves soil health, and maintains ecosystem functions. Implementing this system requires integrating feed use strategies, manure management, and sustainable value chains to increase sustainability while cutting down on resource inputs and waste (McAllister et al., 2025). These integrated strategies, within the framework of "Resilient Livestock and Poultry Production for a Sustainable Food System," show how new biotechnologies, digital monitoring and management tools, and sustainable waste management can work together to create livestock systems that are climate-resilient, productive, and environmentally friendly.

Policy framework

The policy framework and institutional support for resilient livestock systems highlight the need for coordinated, multi-level strategies to boost climate resilience, sustainability, and productivity in livestock production. Key components include facilitating adaptation and mitigation efforts through strong policies, financial incentives, capacity development, and progress in research and innovation (Sohan Vir Singh and Surender Singh, 2023). Effective policy frameworks focus on enhancing climate adaptation and mitigation strategies in livestock by using inclusive approaches that take into account farmer perspectives and socio-economic factors (Avalos et al., 2024). They promote sustainable resource management, food security, poverty reduction, and rural development (Yoon et al., 2025). Priority areas for intervention include climate risk management, supportive regulatory frameworks, and establishing innovation platforms to encourage the widespread adoption of practices that enhance resilience. Policies often incorporate gender responsiveness and social inclusion as crucial aspects to achieve fair outcomes (Habimana, 2024).

Institutional Support Structures

Institutions play an important role by offering technical help, conducting research and development, improving capacity, supporting market access, and encouraging collaboration among different groups (Itcportal, 2025). Strong governance frameworks support coordinated efforts among producers, government agencies, the private sector, and civil society. Examples include initiatives for breeding improvement, feedstock development, vaccination, training in climate-smart practices, and connection to national and international climate finance sources (Fmld, 2025). Integrated institutional frameworks are essential to move beyond fragmented sector strategies and provide coordinated support for sustainable livestock development (Avalos et al., 2024).

Governance and Innovation in Research

Governance frameworks that adapt prioritize ongoing monitoring, assessment, and learning to ensure that policies remain relevant and effective in dealing with changing climate challenges (Emdin et al., 2025). Embracing digital innovation governance, which includes data protection and stakeholder collaboration, is key for complete system transformation. Research progress in genetics, sensor technology, and decision-support tools is driven by policy frameworks that focus on improving resilience and promoting sustainable outcomes. Institutional support also includes frameworks for fair access and inclusion, gender mainstreaming, and restorative justice within resilient livestock policies (Ogoudou et al., 2025; Fao 2025b).

Discussion

At the intersection of sustainability, climate adaptation, and productivity in modern agriculture is the strength of poultry and livestock systems. The health of animals and food supply chains face huge pressure due to climate change, marked by rising temperatures, unpredictable rainfall, and the spread of diseases. This study highlights that in developing and tropical regions, heat stress can greatly reduce the production of meat, milk, and eggs. Millions of people depend on economies centered on animals, and these losses threaten their livelihoods. Precision feeding, genetic selection, and preserving native breeds are essential strategies for balancing animal welfare with productivity. We have entered a new era of data-driven resilience with the integration of technical advances such as precision livestock farming, artificial intelligence, and internet of things-based monitoring. These innovations allow us to detect diseases earlier, maximize feed efficiency, and lessen our environmental impact. Livestock systems can also align with the ideas of a circular bioeconomy through composting and biogas for sustainable waste management. To adapt successfully, support from institutions and policies is still essential. Financial incentives, capacity-building initiatives, and promoting gender-inclusive governance can help adopt climate-smart practices. The One health approach shows that animal, human and environmental health is interconnected. Thus, resilient livestock systems provide a foundation for food security, financial stability in rural areas, and environmental protection, while also serving as a buffer against climate shocks. The future of the global cattle sector relies on the thorough integration of technical, genetic, and institutional progress.

Conclusion

Resilient livestock systems are essential to ensuring global food security amidst climate uncertainty. Achieving resilience requires integrated strategies combining genetics, nutrition, biosecurity, and supportive policies rather than standalone interventions. Adopting digital technologies, precision feeding, and climate-resilient breeding can boost productivity while reducing emissions. Furthermore, promoting a circular bioeconomy lessens resource demands. Enabling these transitions depends on institutional reforms, including farmer education, financing, and equitable governance. By recognizing livestock as a multifaceted pillar of food systems, policymakers can foster a transformative balance between sustainability, equity, and productivity for the 21st century.

Conflicts of interest and financial disclosures

The authors state that there are no conflicts of interest to disclose.

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