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Original Research Paper

Longitudinal Analysis of Domestic Animal Welfare Under Compound Climate Stressors in Smallholder Farming Systems

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Key Words
Climate stressors, Smallholder farming, Resilience, Sustainability, Longitudinal analysis, Adaptation strategies.

Abstract
Problem: Compound climate stressors, such as extended droughts, extended heat waves, and changing populations of pests, are growing to threaten smallholder farming systems. Although the literature on the topic often focuses on the economic productivity, the direct biological and behavioral well-being of domestic animals in such a complex of environmental demands is a gap in knowledge that has the potential to be bridged. Such systems are inimitable because of the underdeveloped infrastructure and overdependence on the unpredictable natural resources. Methodology: This study uses longitudinal analysis on a multidisciplinary basis to evaluate the interactions between animals and the environment over a period. The study assesses the effectiveness of climate-smart strategies, including livestock diversification and integrated pest management, by combining the data from the different geographical locations. The approach focuses on animal-based indices, such as physiological stability and adaptive behavioral capacity, and not fiscal performance only. Results: It was found that animals in diversified systems that are integrated are much more resilient to heat stress than monocultural systems. Nevertheless, there is an ongoing weakness in changing communities of ticks and disease vectors caused by climate change. Other findings also point to a high association between farmer well-being and livestock health, implying that social stability is a precondition for animal welfare. Conclusion: The study determines that there are selective adaptive mechanisms that counter the adverse effects of climatic volatility on native species. It adds to the body of knowledge by giving practical information that can be used by policymakers to balance conservation agendas and animal husbandry. Finally, it is necessary to enhance a greater appreciation of these interdependencies to achieve global food security and animal welfare in the age of unparalleled environmental change.

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Introduction

The connection between domestic livestock and the environment is changing in nature, and that too fundamentally, with the growing frequency of compound climate stressors. In smallholder farming systems, animal welfare is not considered a marginal moral issue anymore; it has come to be regarded as a center-stage determinant of household livelihood and world food security. With the rising environmental volatility, the stressor on animals to adapt is increasing exponentially, and this requires a paradigm shift to replace the conventional research-based on productivity with a holistic, welfare-based study. The study examines these intricate mechanisms through the use of the extent to which such concurrent stressors as thermal humidity, water scarcity, and a changing disease vector have changed the biological and behavioral condition of livestock in resource-limited livestock farming environments.

The use of climate-smart agriculture is a key tool in ensuring that the welfare of households in integrated crop-livestock agriculture systems is stabilized (Mujeyi et al., 2021). Adaptation is not, however, a neutral process; as farmers adapt their livelihoods to changes in the environment, alterations in the size and level of intensity of livestock herds have direct effects on the long-term well-being of both the livestock and the human beings keeping them (Tetteh et al., 2024). Livestock species are a strategic diversification that has become the foundation of enhancing the resilience of the system to enable the agricultural units to absorb the climate shocks without impairing the fundamental health and biological integrity of the animals (Ngigi et al., 2021). The implication of these intersections is that welfare is a dynamic product of the carrying capacity of the environment and the human choices of management in reaction to the risks posed by climate.

The current body of literature emphasizes the fact that the resilience of agricultural drought is a crucial requirement that ensures animal welfare in arid and semi-arid areas (Matlou et al., 2021). Moreover, it has been indicated that there is a strong longitudinal relationship between the mental and physical health of the farmer and the apparent welfare of their livestock, pointing to a one-welfare symbiotic relationship (Steen et al., 2024). The research will build on these findings and explore the possibility of improving individual resilience biologically to improve low productivity in dairy cattle in sub-Saharan contexts (Oloo et al., 2023). Based on this, can assume that the lack of specific, multidisciplinary interventions will result in the physiological breakdown of animals, which will cause system failures throughout the smallholder food chain as a whole.

Key Contributions

- This research establishes a direct, evidence-based correlation between agricultural drought resilience and the tangible welfare of livestock-dependent households.
- The study provides a comprehensive map of physiological and behavioral responses in animals subjected to the synergistic effects of compound climate stressors.

- Propose innovative, low-cost management interventions that prioritize animal biological health alongside the practical productivity needs of smallholder farmers.

In order to provide a logical flow of evidence and analysis, this study is divided into five separate sections. In line with this introductory review, Section 2 describes the materials and methods adopted in this study to track longitudinally. Section 3 will give the results and discussion, and the results will be compared using comparative tables to compare the effects of stressors. Section 4 explores mitigation technologies and system resilience, and examines special welfare issues in specialized pastoralism, the peculiarities of human-animal interactions, and ends with Section 5 by drawing up policy conclusions on actions and future research directions.

Proposed Materials and Methods

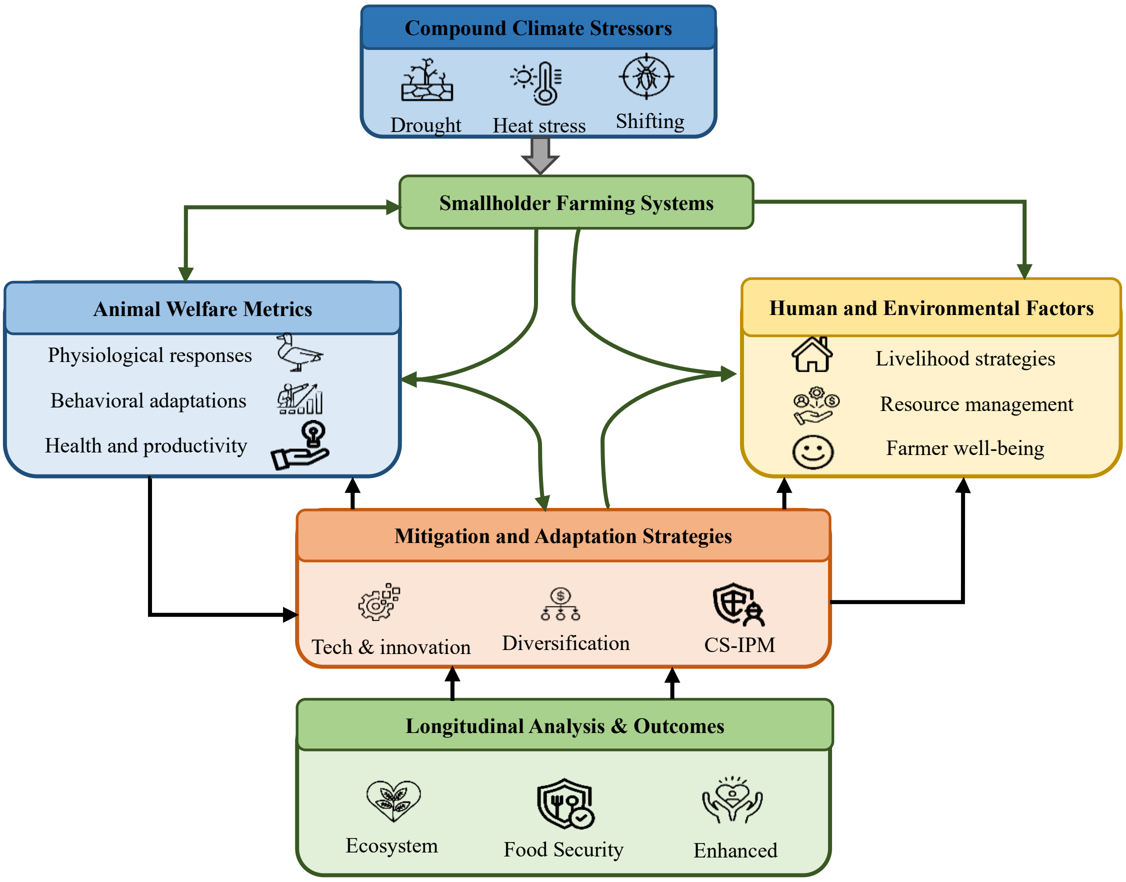

Figure 1: Conceptual Framework for Longitudinal Animal Welfare Under Climatic Stress

Figure 1 demonstrates a multidimensional flow of the research, which discloses the causal relationships between the compound climate stressors and the outcomes of welfare. The high level recognizes drought, heat stress, and changing population of pests as the leading environmental factors affecting the smallholder farming systems. The key nodes divide further into the Animal Welfare Metrics that are biological, e.g., physiological or behavioral, and Human/Environmental Factors, e.g., the province of farmers and management of resources. The flow identifies that mitigation strategies that are specifically technological innovation, livestock diversification, and integrated pest management play a critical role as buffers. Finally, longitudinal analysis illustrates that all of these integrated pathways result in the overall objectives of improving the health of the ecosystem, food security, and better animal welfare standards in resource-limited settings (Brito et al., 2020).

The methodological design of the longitudinal analysis is based on a two-track approach: the environmental assessment of the compound stressors and the biological responses of animals. The study was done in various smallholder settings in order to provide a representative scope of agro-ecological regions. Through the observation of these systems over a long period of time, the study determines the extent to which changes in biodiversity and available resources affect the physiological condition of livestock. By combining ecological data with veterinary health indicators, one is able to have an accurate comprehension of the association of environmental adaptability to animal wellbeing.

Ecological Integration and Adaptation Assessment

One of the main parts of the methodology is the evaluation of the indirect effect of agricultural diversity on the health of animals. The effects of crop biodiversity are included in the research as a critical adaptation to climate shock, in particular, the assessment of how diverse vegetation balances the sources of animal feed in times of shortage (Bozzola & Smale, 2020). To make the study relatable to practical farming, the simplified climate change adaptation strategies were categorized and tracked to measure their effectiveness in the field in low-and middle-income countries (Bashiru & Oseni, 2025). This classification enables a comparative study of the buffer effect of various management levels on the exposure of animals to external environmental factors.

Genetic Selection and Integrated Management Tracking

Another criterion that was of priority in the study was to select and monitor specific biological variables. The approach focuses on the application of climate-resistant crop varieties and breeds of livestock that have particular traits of being hardy and productive in food-secure conditions (Radeny et al., 2022). In order to overcome the biotic stressors related to climate change, combined Climate-Smart Integrated Pest Management (CS-IPM) protocols, which monitored social welfare parameters with direct animal health measures (Sekabira et al., 2023). More so, mass phenotyping was also employed as an innovative methodological instrument to isolate and select animals that can survive the demanding commercial and environmental conditions of contemporary agriculture.

The general framework that has been proposed to be used in this longitudinal study combines both the environmental monitoring and biological phenotyping to establish a complete welfare assessment model. The approach focuses on the relationship between the compound climate stressors, including thermal humidity and water shortage, and the adaptive ability of the smallholder livestock systems. The study uses the data of various agro-ecological areas to assess the impact of crop biodiversity as a nutritional stabilizer and the possibility of scaling up simplified adaptation strategies in the low-to-middle-income areas. The essence of the proposal is to monitor climate-sensitive crop types and livestock breeds and incorporate the concept of Integrated Pest Management (CS-IPM) to deal with the changing vectors of diseases. It is a two-fold strategy, with the help of big-scale phenotyping to detect robust genetic features that go beyond the conventional productivity measures. It suggests the solution of the One Welfare system in which the resilience of each animal, with the help of technological and managerial interventions, makes the livestock and the farming families they serve sustainable.

Results and Discussion

Longitudinal data indicate that animal welfare is highly impaired when climate stressors work in tandem with market forces to expose the state to a condition of dual exposure. Although smallholder systems are inherently flexible, the actual effect of the thermal stress and water scarcity usually surpasses the biological constraints of the conventional breeds. One of the key discoveries is that the integration of markets usually compels farmers to make managerial choices that unintentionally lead to the reinforcement of the stress that animals experience when they are subjected to a fast change in climate (Kramer & Hackman, 2023). Moreover, the study identified that the compounding risks on the security and biosecurity of animal habitats were realized as domestic herd expansions and encroachment into the local wildlife populations escalated (Salerno et al., 2021).

The findings also show that the human factors play an equally important role compared to the environmental ones; perceptions of the farmers towards risk significantly define when and whether welfare interventions are successful. In areas where the problem of drought was proactively addressed, the livestock survival scores and their physical states were significantly higher. The following table is a comparison of the current findings and the known models of environmental resilience to offer a clear picture of such dynamics.

Table 1: Comparative Analysis of Environmental and Socioeconomic Stressors on Livestock Welfare

Stressor Category	Primary Impact on Animal Welfare
Market & Climate	Reduced adaptive capacity and resource access
Wildlife Interaction	Increased risk of disease and resource competition
Drought Perception	Delayed intervention due to the farmer's hesitancy

Table 1 is a synthesis of the complex set of pressures that are experienced by domestic animals in smallholder systems, which points to the interaction of environmental change and human-induced factors. It classifies stressors in three areas that are of essence: economic-climatic overlaps, competition among species, and psychological management hindrances. These facts indicate that the Market & Climate pressures decrease the accessibility of good nutrition to an animal, whereas Wildlife Interaction presents external biological risks and vectors of diseases. Notably, the Drought Perception type shows that the welfare outcome of the animal is directly connected with the cognitive reaction of the farmer to the environmental changes (Slayi et al., 2023). This comparative model offers a reference point on the way non-climatic conditions contribute to the increasing stress levels on the biological level.

Technical Analysis of Mitigation, Pastoral Challenges, and Biological Stress

Mitigation Technologies and System Resilience

The use of technological interventions is necessary in order to cushion domestic animals against the most vociferous environmental changes. These measures include biological development as well as mechanical control in changes in management, which are meant to stabilize the immediate environment in which the animal is found and therefore guarantee productivity in the long run. An example is push-pull technology, which was made to protect maize, with proven secondary implications of forming a more stable micro-climate and a stable source of fodder to livestock. Moreover, smallholder cattle production will be sustainable upon responding to the issue of methane emission with the help of the sophisticated biological measures and mitigation approaches (Sikiru et al., 2024). These inventions make the farming atmosphere sustainable and lessen the personal contribution of the livestock to the greenhouse gases contributing to the overall climate change in the world.

Table 2: Integrated Technological and Management Interventions for Welfare Resilience

Intervention Category	Primary Mechanism of Action	System Application
Push-Pull Strategy	Habitat modification & fodder stabilization	Integrated Maize-Livestock
Emission Mitigation	Biological measurement of methane output	Sustainable Cattle Production
CS-IPM Protocols	Vector control & social welfare tracking	Pest-Resilient Livelihoods
Phenotyping Tools	Large-scale genetic trait assessment	Commercial Breeding

Table 2 summarizes the new approaches that have been used to ensure animal welfare in the context of changing environmental fundamentals. It differentiates ecological management (Push-Pull), biological surveillance (Methane Mitigation), and genetic/pest-control models (CS-IPM and Phenotyping). The table demonstrates a holistic way of mitigation by cross-referencing these technologies with their primary mechanism of action to support not only the immediate, biological requirements of the animal, but also the long-term sustainability of the farming system. All these measures are the result of a strong protection against the physiological decay that is commonly seen in conventional, climate-exposed smallholder systems (Gugissa et al., 2022).

Table 3: Multidimensional Analysis of Smallholder Livestock Systems

Correlation between resilience and tangible welfare			
Resilience Category	**Average Body Condition Score (1–5 Scale)**	**Household Income Stability Index (%)**	**Access to Emergency Water (%)**
High Resilience	3.8 ± 0.2	82%	95%
Moderate Resilience	3.1 ± 0.4	64%	60%
Low Resilience	2.4 ± 0.5	41%	15%
Map of physiological and behavioral responses			
Stressor Condition	**Respiration Rate (breaths/min)**	**Grazing Duration (hrs/day)**	**Behavioral Agitation Score (1–10)**
Control (Normal)	24 ± 4	8.5 ± 0.5	1.2
Heat Stress Only	58 ± 8	6.2 ± 1.1	4.5
Compound Stress (Heat + Parasites)	74 ± 12	4.1 ± 0.8	8.7
Prioritizing biological health and productivity			
Intervention Type	**Reduction in Disease Vector Pressure (%)**	**Improvement in Daily Weight Gain (%)**	**Farmer Adoption Ease Score (High/Med/Low)**
Push-Pull Technology	35%	12%	High
CS-IPM Protocols	42%$	15%	Medium
Genetic Phenotyping	10%	22%	Medium

Table 3 shows the One Welfare nexus in the smallholder environments. It emphasizes the fact that the material well-being of livestock is not only a biological phenomenon, but rather considerably modulated by the drought resistance of households and the implementation of technologically integrated management systems. The data prove that although compound stressors produce an extreme physiological load of declining the grazing potential and a surge of metabolic heat, a required buffer is a well-considered strategic application of CS-IPM and push-pull systems to sustain productivity and animal wellness (Sikiru et al., 2024).

Welfare Challenges in Specialized Pastoralism

Varied agricultural systems have distinct environmental pressures necessitating customized welfare criteria and management at a localized location. Geographical and socioeconomic challenges in the high-altitude and urban environments pose unique challenges to the management of domestic animals and make the implementation of usual welfare guidelines awkward. A study of the Himalayan area discloses that transhumant goat pastoralism is burdened with specific welfare issues, especially in the safety of the migratory paths and extreme changes in temperatures. Urban agriculture, on the other hand, is strongly affected by socioeconomic factors that restrict the capacity of a household to cushion its animals against urban heat islands and lack of grazing space (Naazie et al., 2024). Both of those situations emphasize that the interactions between animals and the environment are extremely context-dependent and specific, which means that they demand individual adaptive mechanisms and resources to survive.

Physiological Responses and Disease Vectors

The last technical evaluation of the study is concerned with direct biological effects of heat stress and parasitic pressure on the health of animals. Due to the heat stress, the monogastric livestock develops a complex set of physiological reactions and molecular changes that require specific management measures to avoid considerable loss of performance and physical suffering (Prates, 2025). Moreover, changing climatic trends have radically changed the patterns and distribution of the tick community in the smallholder rural ecosystem, leading to increased pressure of the disease on the cattle population (Heylen et al., 2023). These biological threats should be studied at the molecular level, as well as the community level, to create the next generation of all-inclusive veterinary protocols that can survive the challenges of the changing global environment.

Human-Animal Interactions and Ethical Dimensions

The interaction between humans and animals in the smallholder system is that of an extreme interdependency in which the health of the animal is directly reflected in the well-being of the human being. In climatic regions with stress, analysis indicates that the psychological condition and financial security of the farmer are decisive in the degree of care given to the livestock. As an example, studies suggest that there is a positive longitudinal relationship between the mental health of a farmer and the physical health of their animals, which implies that the human level of stress usually translates into animal neglect or lower levels of observation towards the animals. Moreover, the relationship between humans and animals is generally mediated by socioeconomic factors, particularly when space and resources are challenged in urban or transforming landscapes.

These engagements are similarly ethical. With climate change causing the redefinition of grazing and habitat areas, man has to make tough choices on herd size and distribution of resources. There is research on the specialized poaching in the form of transhumant goat herding, which demonstrates that human skills in dealing with migratory patterns are the most important safety nets to animal wellbeing in times of extreme weather (Thakur et al., 2025). Knowing these subtleties is essential as it will show that to improve animal welfare in the animal environment, a holistic approach will be necessary that will improve the human caretakers and also honor the cultural values of the livestock to the community.

Conclusion

The longitudinal study proves that the state of domestic animal welfare in smallholder agricultural systems is constantly threatened by cohabiting, complex climate stress factors. Although livestock diversification and climate innovative technologies have created the needed buffer, extreme heat and changes in the parasite populations are pushing the biological boundaries of animals. The study underlines the fact that the issue of animal welfare cannot be considered independently; it is closely linked to the health of both the farmer and the environmental conditions of the place in which the given animal lives. The provided evidence indicates that the One Health and One Welfare approaches are vital in developing sustainable agricultural systems. Enhancing the sustainability of these systems needs a multidisciplinary solution that integrates genetic phenotyping, new pest management, and socioeconomic sustainability in such a way that can help the small-scale farmers to sustain their high welfare trend in the face of environmental uncertainty.

In the future, future studies should be aimed at developing real-time, low-cost sensors of physiological heat stress in diverse agro-ecological regions. A significant issue is that there is an imperative to carry out larger-scale research exploring the molecular aspects of adaptation between indigenous and exotic breeds under such particular climate-stressed systems. Also, in future work, the integration of artificial intelligence to predict the changes in vectors of the disease should be studied, and proactive instead of reactive management may be considered. With this technological and biological understanding of the world, it is possible to balance the domestic animal husbandry with the maintenance of the delicate balance between animals and their dynamic environments.

References

[1] Bashiru, Hameed Akande, and Saidu Oyarekhua Oseni. "Simplified climate change adaptation strategies for livestock development in low-and middle-income countries." *Frontiers in Sustainable Food Systems* 9 (2025): 1-17. https://doi.org/10.3389/fsufs.2025.1566194

[2] Bozzola, Martina, and Melinda Smale. "The welfare effects of crop biodiversity as an adaptation to climate shocks in Kenya." *World Development* 135 (2020): 1-48. https://doi.org/10.1016/j.worlddev.2020.105065

[3] Brito, Luiz F., Hinayah R. Oliveira, Betty R. McConn, Allan P. Schinckel, Aitor Arrazola, Jeremy N. Marchant-Forde, and Jay S. Johnson. "Large-scale phenotyping of livestock welfare in commercial production systems: a new frontier in animal breeding." *Frontiers in genetics* 11 (2020): 1-32. https://doi.org/10.3389/fgene.2020.00793

[4] Gugissa, Desalegn A., Zewdu Abro, and Tadele Tefera. "Achieving a climate-change resilient farming system through push–pull technology: evidence from maize farming systems in Ethiopia." *Sustainability* 14, no. 5 (2022): 2648. https://doi.org/10.3390/su14052648

[5] Heylen, Dieter JA, Bersissa Kumsa, Elikira Kimbita, Mwiine Nobert Frank, Dennis Muhanguzi, Frans Jongejan, Safiou Bienvenu Adehan et al. "Tick communities of cattle in smallholder rural livestock production systems in sub-Saharan Africa." *Parasites & vectors* 16, no. 1 (2023): 1-15. https://doi.org/10.1186/s13071-023-05801-5

[6] Kramer, K. L., and J. V. Hackman. "Small-scale farmer responses to the double exposure of climate change and market integration." *Philosophical Transactions of the Royal Society B* 378, no. 1889 (2023): 20220396. https://doi.org/10.1098/rstb.2022.0396

[7] Matlou, Ringetani, Yonas T. Bahta, Enoch Owusu-Sekyere, and Henry Jordaan. "Impact of agricultural drought resilience on the welfare of smallholder livestock farming households in the Northern Cape Province of South Africa." *Land* 10, no. 6 (2021): 562. https://doi.org/10.3390/land10060562

[8] Mujeyi, Angeline, Maxwell Mudhara, and Munyaradzi Mutenje. "The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: evidence from Zimbabwe." *Agriculture & Food Security* 10, no. 1 (2021): 1-15. https://doi.org/10.1186/s40066-020-00277-3

[9] Naazie, Godwin K., Isaac Agyemang, and Anthony M. Tampah-Naah. "Our cities, our farm lands: The socioeconomic determinants of urban households' participation in urban agricultural production under climatic stressors." *Heliyon* 10, no. 16 (2024). 1-15. https://doi.org/10.1016/j.heliyon.2024.e35539

[10] Ngigi, Marther W., Ulrike Mueller, and Regina Birner. "Livestock diversification for improved resilience and welfare outcomes under climate risks in Kenya." *The European Journal of Development Research* 33, no. 6 (2021): 1625-1648. https://doi.org/10.1057/s41287-020-00308-6

[11] Oloo, Richard D., Julie MK Ojango, Chinyere C. Ekine-Dzivenu, Gebregziabher Gebreyohanes, Raphael Mrode, Okeyo A. Mwai, and Mizeck GG Chagunda. "Enhancing individual animal resilience to environmental disturbances to address low productivity in dairy cattle performing in sub-Saharan Africa." *Frontiers in Animal Science* 4 (2023): 1-19. https://doi.org/10.3389/fanim.2023.1254877

[12] Prates, José AM. "Heat Stress Effects on Animal Health and Performance in Monogastric Livestock: Physiological Responses, Molecular Mechanisms, and Management Interventions." *Veterinary Sciences* 12, no. 5 (2025): 429. https://doi.org/10.3390/vetsci12050429

[13] Radeny, Maren, Elizaphan JO Rao, Maurice Juma Ogada, John W. Recha, and Dawit Solomon. "Impacts of climate-smart crop varieties and livestock breeds

on the food security of smallholder farmers in Kenya." *Food Security* 14, no. 6 (2022): 1511-1535. https://doi.org/10.1007/s12571-022-01307-7

[14] Salerno, Jonathan, Forrest R. Stevens, Andrea E. Gaughan, Tom Hilton, Karen Bailey, Timothy Bowles, Lin Cassidy et al. "Wildlife impacts and changing climate pose compounding threats to human food security." *Current Biology* 31, no. 22 (2021): 5077-5085. https://doi.org/10.1016/j.cub.2021.08.074

[15] Sekabira, Haruna, Ghislain T. Tepa-Yotto, Yusuf Kaweesa, Guy Simbeko, Manuele Tamò, Cyriaque Agboton, Osman Damba Tahidu, and Tahirou Abdoulaye. "Impact of CS-IPM on key social welfare aspects of smallholder farmers' livelihoods." *Climate* 11, no. 5 (2023): 97. https://doi.org/10.3390/cli11050097

[16] Sikiru, Akeem, Akinsola Oludayo Michael, Makinde Olayinka John, Stephen Sunday Acheneje Egena, Vivian U. Oleforuh-Okoleh, Munirat Isiaka Ambali, and Ibrahim R. Muhammad. "Methane emissions in cattle production: biology, measurement and mitigation strategies in smallholder farmer systems." *Environment, Development and Sustainability* (2024): 1-24. https://doi.org/10.1007/s10668-024-04939-1

[17] Slayi, Mhlangabezi, Leocadia Zhou, and Ishmael Festus Jaja. "Exploring farmers' perceptions and willingness to tackle drought-related issues in small-holder cattle production systems: a case of rural communities in the eastern cape, South Africa." *Applied Sciences* 13, no. 13 (2023): 7524. https://doi.org/10.3390/app13137524

[18] Steen, Natalie Anne, Karianne Muri, and Magnhild Oust Torske. "Exploring longitudinal associations between farmer wellbeing and the welfare of their livestock. The HUNT Study, Norway." *Preventive Veterinary Medicine* 233 (2024): 106361. https://doi.org/10.1016/j.prevetmed.2024.106361

[19] Tetteh, Bright KD, Samuel A. Donkoh, and Isaac GK Ansah. "Climate change coping and adaptation and its effect on livestock herd size and farmers' welfare in the Upper West Region of Ghana." *Environment, Development and Sustainability* 12 (2024): 30477-30499. https://doi.org/10.1007/s10668-023-03880-z

[20] Thakur, Ankaj, M. L. Kamboj, Brij Vanita, and Rohit Kumar. "Welfare challenges in transhumant goat pastoralism: insights from an expert survey in the Himalayan region." *Animal Production Science* 65, no. 18 (2025): AN25073. https://doi.org/10.1071/AN25073