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FOOD SECURITY AND LIVESTOCK: A COMPREHENSIVE REVIEW OF SUSTAINABILITY, CHALLENGES AND INNOVATIVE SOLUTIONS

Syda Zile Huma Naqvi[1], Bakhtawar Maqbool[2], Muhammad Imran Arshad[3], Ayodeji Aderibigbe[4] and Shafia Tehseen Gul [1,4]*

[1]Department of Pathology, Faculty of Veterinary Science, University of Agriculture, Faisalabad-38040, Pakistan
[2]Department of Pathobiology, College of Veterinary and Animal Sciences, Jhang, Pakistan
[3]Department of Epidemiology and Public Health, University of Agriculture, Faisalabad-38040, Pakistan
[4]College of Agriculture and Food Sciences (CAFS), Florida A&M University, Tallahassee, FL 32307, USA

*Corresponding author: drshafia66@yahoo.com; dr.shafia.gul@uaf.edu.pk

ABSTRACT

Livestock systems are a significant concern for global food security, providing basic nutrition and livelihoods while also posing serious environmental problems. The dual functions of livestock are revealed in this review, i.e., they are essential for billions of animal-derived foods that contribute to livelihood and nutrition, but they also promote climate change and resource degradation. Smallholder systems within middle- and low-income countries operate to assist communities, including women, through poverty reduction and stunting elimination, but are vulnerable to environmental stress. Industrial systems within high-income countries often prioritize efficiency at the expense of exacerbating inequalities and environmental degradation. Animal-derived foods are rich in nutrients and essential for proper growth and development. However, with the rapid increase in population, the rising demand for meat and dairy products raises sustainability concerns, particularly given the significant contribution of livestock to greenhouse gas emissions and resource consumption. But their implementation requires strategic planning and sustained investment. To reconcile livestock uses with environmental needs, an integrated approach is needed, comprising climate-smart subsidies and carbon pricing. Future research should focus on livestock systems that are resilient to climate change, provide impartial access to technology, and incorporate aspects of health and disease resistance to reduce the risk of Zoonoses. Livestock will eventually play a central role in food security, and their sustainable future depends upon the unification of traditional knowledge and science and making food policies more reasonable.

***Keywords*:** Livestock; Food security, Sustainability, Climate change, Animal source food (ASF)

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1. INTRODUCTION

According to the Food and Agriculture Organization (FAO) of 2021, livestock systems directly contribute to employment and income, supporting approximately 1.3 billion people worldwide. Livestock systems also account for 40% of agricultural GDP (Gross Domestic Product) and 34% of the world's protein supply. Food security is defined by the FAO as a condition where every Human being, at any given time, has access to physical, social, and economic resources that can provide adequate, safe, and healthy food. Food security is perhaps one of the most pressing issues that remains unsolved (Leroy et al., 2022). With population growth, climate shifts, and geopolitical disruptions, livestock systems have become an integral component of the multitude of food security frameworks worldwide (Beal et al., 2023). Livestock covers all four pillars of food security: availability, access, utilization, and stability (Leroy et al., 2022). Their importance is not limited to food production alone, but also encompasses economic, social, and environmental aspects, making them an essential component of both global and national food systems (Abu Hatab et al., 2022).

Animal source foods (ASFs), such as meat, milk, and eggs, are also incredibly nutritious foods that contain the essential building blocks of life, including vitamins, micro- and macro-minerals (Beal et al., 2023). These Animal-derived foods account for 18% of global caloric intake and meet 34% of the protein needs. According to the World Health Organization (WHO) in 2022, Animal-derived foods, especially milk, provide the necessary calcium and cover 14% of dietary needs. Studies suggest that a deficiency of livestock-derived protein is linked to stunting and high anemia rates among children and women, especially during pregnancy in low-income countries (Smith et al., 2013).

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Livestock provides resilience, too, beyond nutrition (Abu Hatab et al., 2022). They serve as living investments for smallholder farmers, providing a barrier against crop failures and economic losses (Shahbaz et al., 2022). Livestock play a key role in diversifying diets and achieving health benefits in sub-Saharan Africa and South Asia, provided that 20–50% of total household income is allocated to them (Kolawole et al., 2022). In addition, livestock by-products, such as manure as a fertilizer, hides for the textile industry, and draft power for plowing, boost their value chain footprint. For example, manure is used to enhance soil fertility on 60% of the world's agricultural land, thereby reducing their dependence on synthetic fertilizers (Choi et al., 2017; USDA, 2023).

However, livestock's role is a double-edged sword. Thus, they strengthen food security; however, such unsustainable practices undermine environmental stability (Singh et al., 2023). Livestock contribute 14.5% of greenhouse gas emissions due to anthropogenic practices in livestock rearing and production, and are responsible for rainforest deforestation, while livestock farming uses 30% of the freshwater resources globally (Hoekstra et al., 2012). Ethical worries about intensive farming and the risks of diseases jumping from animals to humans make their story even more complex. Finding a balance between high output and long-term sustainability is crucial to determining how livestock can contribute to and support food security (Abu Hatab et al., 2021).

Emerging issues related to livestock production highlight the need for incorporation. Alternative proteins, such as plant-based and lab-grown meats, challenge traditional livestock-derived meat and protein sources; however, their scalability and acceptance in LMICs (Low- and Middle-Income Countries) remain unclear (Abu Hatab et al., 2022). Climate adaptation, particularly the role of livestock in climate-resilient farming, is less studied than mitigation strategies (Bano et al., 2024). The COVID-19 pandemic highlighted zoonotic risks, underscoring the need for integrated livestock management practices (Abu Hatab et al., 2021).

This article reviews studies on the role of livestock in enhancing food security and sustainability. It will examine the effects of livestock on nutrition, economics, and the environment in several farming regions worldwide. Finally, it will propose methods to ensure that livestock farming is both fair and sustainable, contributing to food security. This review focuses on monogastric (poultry, pigs) and ruminant (cattle, goats, sheep) animals across small household and industrial setups. It discusses the role of farm animals in helping alleviate poverty in low- and middle-income countries, while also examining global trends. By integrating a multidisciplinary approach, this review provides a roadmap for leveraging livestock systems to achieve the Sustainable Development Goals, specifically zero hunger, without compromising terrestrial boundaries.

2. LIVESTOCK CONTRIBUTION TO FOOD SECURITY

Livestock products are unmatched in their efficiency in providing essential nutrients that are readily metabolized by the human body (González et al., 2020). In high-income countries, animal-source food constitutes about 60-80% of the diet, while in low- and middle-income countries (LMICs), it accounts for 20-30%, serving as a crucial component of plant-based diets (Lokossou et al., 2021). Additionally, animal-derived foods are the only dietary source that contains all nine amino acids necessary for growth and immune function (González et al., 2020). For example, the egg's protein digestibility corrected amino acid score is 1, the highest among all other food products (Iannotti et al., 2014). Vitamin B12 is one of the essential micronutrients available in animal-derived foods; its scarcity affects 15–40% of the global population, including vegans and the elderly (Smith et al., 2013). Iron and Zinc, the essential Micronutrients, are not a debatable topic in terms of their importance for human health. Meat containing heme iron, which is 2–3 times more bioavailable than iron from plants, has been shown to lower anemia levels in children (Silva et al., 2025). One of the most important micronutrients is calcium. Calcium requirements are met by 70% of the population through dairy consumption (Global Nutrition Report, 2021; USDA, 2024). Table 1 presents the key animal products of each country, along with their GDP share of livestock in the year 2023-24.

Livestock systems play a crucial role in economic development, particularly in agricultural economies, as they generate more than half of agricultural GDP, employment, and support rural livelihoods. Livestock production accounts for approximately 40% of the total agricultural GDP worldwide, and this figure increases to 60% in pastoralist communities, such as those in East Africa (Lane et al., 2025). According to a 2021 FAO report, livestock production not only plays a macroeconomic role but also supports the livelihoods of approximately 1.3 billion individuals worldwide, including smallholder farmers, processors, and traders. Livestock keeping is also a principal poverty-reduction strategy through the diversification of income. Studies show that livestock-owning households have a 35% lower chance of falling into poverty, further emphasizing the importance of this sector in strengthening economic resilience (Elzaki et al., 2019). Thus, livestock systems not only promote economic growth but also facilitate financial and social stability within rural society (Conrad et al., 2018).

2.1. Challenges Faced by Livestock Production and Food Security

Climate change is detrimental to livestock sustainability through its impact on temperature rise and variability

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in rainfall patterns, consistently affecting both livestock production and resource value. Heat stress, for example, has been reported to decrease dairy production among dairy animals by 10–25% and poultry egg production by approximately 20%, suggesting that livestock systems are susceptible to high temperatures (Kauffman et al., 2022). Moreover, prolonged droughts lead to feed shortages, with disastrous effects on pastoralist communities. For instance, in 2020 and 2023, the Horn of Africa was hit by ferocious droughts that killed approximately a crore of animals, draining millions of resources for cattle farmers to sustain their livelihoods (FAO, 2023). Additionally, livestock production is the most significant source of greenhouse gas emissions, with ruminants, such as cattle, contributing to almost 80% of the sector's total emissions, primarily through intestinal fermentation (Kyttä et al., 2025). Kyttä et al. (2025) demonstrated that these issues underscore the importance of climate-resilient animal management practices in achieving long-term sustainability and food security.

Table 1: Livestock share (%) in GDP of different countries during 2023-2024 to their national economy and their livestock products, which shows the liking of each nation for animal-source food

Country	Share (%) in GDP	Key Livestock Products	References
Mexico	19.6	Pork, Poultry, and Beef	Avalos et al. (2024); Zaldivar-Gomez et al. (2024)
Ethiopia	19,0	Cattle, Sheep, and Goat meat	Ali et al. (2024)
Pakistan	14.2	Beef, sheep, Dairy, and Poultry	Adebayo et al. (2024)
Nigeria	10,0	Poultry, Beef, and Goat Meat	Adebayo-Oke et al. (2024)
Argentina	9.83	Beef and Dairy	Borges et al. (2024)
Canada	7.0	Dairy, Pork, and Poultry	Sadiku et al. (2024)
China	6.8	Pork, Poultry, and Eggs	Zhou et al. (2024)
New Zealand	6.4	Dairy, Sheep, and Beef	Chapman et al. (2024)
Brazil	6.24	Beef, Poultry, and Pork	Mendes et al. (2024)
India	6.1	Milk, Beef, and Poultry	Mitra et al. (2023)
Kenya	5.2	Dairy, Beef, and Goat Meat	Anno (2025)
Russia	3.35	Dairy, Beef, and Pork	Abdikerimova et al. (2024)
South Africa	2.9	Beef, Poultry, and Sheep	Monteiro & Jammer (2024)
Australia	2.4	Beef, Sheep, and Wool	Anderson (2024)
Bangladesh	1.85	Poultry, Beef, and Milk	Ratna et al. (2024)
France	1.3	Beef, Pork, and Dairy	Meunier et al. (2024)
Germany	0.8	Pork, Dairy, and Poultry	Kleingräber & Efken (2025)
United States	0.8	Beef, Pork, Dairy, and Poultry	World Food and Agriculture – Statistical Yearbook (2023)
United Kingdom	0.5	Beef, Dairy, and Sheep meat	Hinchliffe et al. (2024)

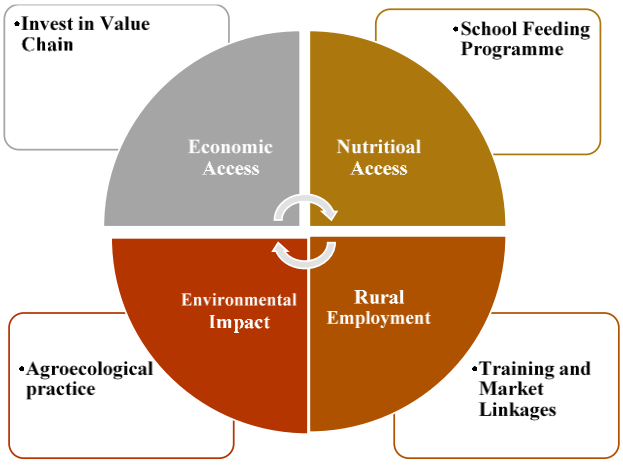

Fig. 1: A Linkage showing conflicts about food security and their solution.

Livestock-derived zoonotic diseases are a momentous threat to global health, food security, and economic stability and require vigorous biosecurity measures. Avian influenza, the H5N1 epidemic 2021–2023, resulted in the getting rid of about 140 million poultry birds, generating a 60% increase in egg prices in the United States, which is an attestation to the far-reaching economic consequence of disease epidemics (World Bank Annual Report, 2023; Subedi et al., 2024). Equally, African swine fever ruined the world pork corporation, killing 50% of China's pigs in 2019 and causing devastation across global meat supply chains (WOAH 2020; Cheng & Ward, 2022). Besides unexpected epidemics, the disproportionate use of antibiotics in rigorous animal production gave rise to antimicrobial resistance (Hannan et al., 2024), a forthcoming emergency that will kill 10 million people every year by 2050 if not tackled (Liang et al., 2023). They highlight the inevitability of stringent biosecurity, appropriate disease management practices, and international collaboration in plummeting the potential hazards from zoonotic disease agents and firming up global food chains. As illustrated in Fig. 1, the complex relationship between conflicts effecting food security and potential solutions highlights the need for integrated approach.

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2.2. Strategies for Sustainable Livestock Production and Food Security

Technological innovations in animal husbandry practice, i.e., precision livestock farming and genetic modification, are revolutionizing efficiency, enhancing disease resistance, and improving environmental stability. Precision Livestock Farming (PLF) utilizes devices and artificial intelligence to monitor animal health and optimize resource utilization. For example, wearable sensors for dairy cattle have been used to reduce mastitis occurrence by 30%, improve animal well-being, and increase yield (Liu et al., 2019). Moreover, technological advances in the feed-making process, such as the incorporation of methane inhibitors like 3-nitrooxypropanol (3-NOP), have resulted in a 30 percent reduction in methane emissions from livestock without compromising milk production, thereby encouraging livestock system sustainability (Homem et al., 2024). Fig. 2 informs that these advancements imitate the prowess of innovation in adapting livestock efficiency, resistance to disease, and environmental stability.

Policy measures have a significant role in influencing the sustainability, economic performance, and environmental interconnectedness of animal production through some principles and trade policies (Pham-Khanh et al., 2024). Table 2 illustrates administrative subsidies supporting climate-resilient livestock management, as in some countries, have introduced the Climate-Smart Livestock program, which encourages the uptake of drought-resistant forage crops, offering commercial and food security benefits to approximately 500,000 pastoralists (Lopez-Ridaura et al., 2018). Furthermore, mechanisms of carbon assessment, such as the one proposed by the European Union, which imposes a tax on methane, provide monetary incentives for emissions reduction in beef and dairy animal farming, as well as more justifiable modes of production. Trade policy also has a considerable influence on the production price of livestock as well as market trustworthiness (Lovarelli et al., 2023). As we have witnessed, the elimination of import duties on chicken feed in Egypt reduced chicken production costs by 15%, illustrating the success of openness in promoting competitiveness and industry productivity (Iannotti et al., 2014). Overall, these policy reforms demonstrate the merit of regulatory intervention in fostering the development of a more sustainable, economically robust, and efficient livestock industry.

Table 2: Research-based findings and policy implementation of livestock's multidimensional role

Feature	Status	Policy Implementation	References
Economic Aspect	Livestock accounts for 40% of agrarian GDP in Sub-Saharan Africa, thereby supporting smallholder incomes.	Capitalize in livestock value chains (e.g., feed and feeding systems, cold storage) to stabilize revenues and reduce poverty.	The State of Food Security and Nutrition in the World (2022)
Nutritional Aspect	Daily intake of ASFs reduces child stunting by 24 percent in pastoralist communities.	Integrate ASFs (e.g., milk, eggs) into institute feeding programs and maternal health initiatives.	Grace et al. (2018)
Environmental Aspect	Ruminant livestock accounts for 14.5 percent of global greenhouse gas (GHG) emissions, but mixed crop-livestock systems can sequester carbon.	Endorse agroecological does (e.g., silvo-pasture, compost recycling) to balance efficiency and sustainability.	Masson-Delmotte et al. (2019)
Even-headedness	Women own 60–80% of livestock in LMICs but possess <10% of land titles, limiting access to credit.	Support women's land rights and provide gender-responsive monetarist tools (e.g., assemblage loans).	Njuki et al. (2022)
Climatic Resilience	Drought-resistant livestock breeds (e.g., Boran cattle) upsurge household resilience by 30% during climate shocks.	Scale up breeding agendas and insurance structures for climate-adapted livestock species.	Thornton et al. (2009)
Rural Employment	Livestock generates 130 billion jobs worldwide, 70% of which are in informal sectors.	Solemnize informal livestock areas through training, safety grids, and market links.	ILO Flagship Report (2021)
Cross-Sectoral Policy	Only 15% of national food security policies openly address livestock.	Develop cohesive policies linking livestock, agriculture, and nutrition for general food security.	World Bank Annual Report (2023)

Fig. 2: Actions to be prioritized by stakeholders for Food Security.

Livestock systems are an imperative component of global food security, economic progress, and human nutrition but are confronted with the most serious challenges such as climate change, scarcity of resources, and

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environmental hazards (Kyttä et al., 2025). Increased temperature, water and feed shortages, and dangerous levels of greenhouse gas emissions require adaptive actions such as drought-tolerant breeds, precision livestock farming, and improved pasture management. Though animal-source foods provide essential nutrients, their environmental impacts underscore the importance of adopting balanced diet strategies that incorporate sustainable livestock development (Homem et al., 2024). Fig. 2 highlights the areas that stakeholders for sustainable livestock production should prioritize.

Additionally, ensuring access to innovations such as Precision livestock farming and agricultural insurance to smallholder farmers is vital in constructing equitable and adaptable livestock systems (Pollard & Booth, 2019). This review synthesizes the existing understanding of the interlinkages among livestock production, environmental sustainability, and socio-economic equity, with a focus on optimizing productivity without adverse effects. Through the integration of scientific progress with policy reaction, the review reveals the need for integrated methods to facilitate sustainable livestock development in the face of global challenges.

2.3. Livestock Innovation for Sustainable Food Security

There are extreme regional and systemic variations regarding the role of livestock in nutrition, economic development, and environmental sustainability (Pollard & Booth, 2019). Nutritionally, animal-source foods are widely regarded as a key to preventing micronutrient malnutrition in all settings, but particularly in low-resource settings. Randomized controlled trials in Kenya and Bangladesh have demonstrated that daily egg intake can prevent stunting in children by 15–20% (Iannotti et al., 2014; Headey et al., 2018). However, controversies persist regarding the optimal intake of ASF, with high-income countries concerned about ASF overconsumption leading to non-communicable diseases, and LMICs by under-consumption (Mapes et al., 2022). From an economic perspective, livestock farming is a vital source of livelihood and resilience, particularly for smallholder systems. However, industrial livestock production systems in high-income countries with high production levels are often tilted towards marginalizing small producers, raising concerns regarding equity (HLPE, 2022). Environmentally, there is widespread consensus on the high carbon intensity of ruminant livestock, with beef having 6–10 times higher per kilogram greenhouse gas emissions than poultry (Conrad et al., 2018). However, regional differences persist: extensive grazing in Sub-Saharan Africa has a lower emissions intensity but a larger land use, while intensive U.S. feedlots have the highest land use intensity, albeit at the expense of water pollution (Eska et al., 2024). These studies reflect the multifaceted nature of the role of livestock in sustainable food chains, which require region-specific interventions to address nutrition, economic equity, and environmental sustainability. Fig. 3 sums up the timeline of policies and research milestones highlights crucial advancements in livestock sustainability supporting food security initiatives.

Fig. 3: Timeline (2023-2030) for Policy and Research Milestones in Sustainable Livestock.

The available literature on livestock systems and food security reveals numerous contradictions. It highlights significant knowledge gaps, most notably in climate adaptation measures, alternative protein intake, and preparedness for facing zoonotic disease outbreaks (Lake et al., 2012). Agroecological sustainable silvopasture is one area of research that focuses on enhancing climatic durability, while others promote technical solutions, including the use of methane inhibitors; again, there is minimal evidence for tackling scalability and feasibility in developing countries (Eska et al., 2024). Analogously, alternative proteins like cultured meat are highly controversial in high-income countries. Furthermore, there is a lack of empirical evidence on cultural acceptability and market accessibility for these in low- and middle-income countries (LMICs), where insect protein faces fewer sociocultural barriers (Kim et al., 2022). Again, zoonotic disease risk research is unevenly concentrated in other regions (Kim et al., 2022). Preparedness for Avian Influenza epidemics is comparatively good in Asia, while Africa's open markets for livestock indicate a high level of deficits in surveillance and response capabilities (DFID, 2012). Filling these gaps is imperative to design equitable and region-specific measures for sustainable livestock

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production and food security at the global level (Lake et al., 2012; Kyttä et al., 2025).

To enhance the value of livestock systems, a comprehensive research strategy and innovative approaches are crucial for improving production efficiency. Developing long-term sustainability indicators, such as net nutritional benefit per environmental cost, is crucial for evaluating diverse livestock systems (Windsor, 2021). Resilience modeling is crucial for understanding how climate change will impact livestock in the event of a 2°C or 4°C temperature rise, enabling the selection of optimal adaptation strategies (Lovarelli et al., 2023).

Despite the wide-ranging literature on livestock and food security, critical knowledge gaps persist. Existing studies often fragment discussions into isolated themes, such as nutritional needs, economic impacts, or environmental impacts, rather than adopting an integrated systems approach to livestock production. Few studies resolve the tension between livestock's indispensable benefits and their sustainability challenges, particularly in the context of climate change and fluctuating dietary trends. ASFs are vital for nutrient-deficient populations, but high-income countries face criticism for overconsumption and their ecological interconnectedness. This review bridges these contradictions by offering a balanced analysis that enlightens the policy and innovation needed.

3. CONCLUSION

Livestock systems play a vital role in global food security by providing essential nutrition, economic benefits, and cultural values; however, they also pose specific environmental and ethical challenges. For billions of people, ASF's are a critical source of nutrients and livelihoods. In LMICs, smallholder livestock help alleviate poverty and malnutrition but also exert pressure on fragile ecosystems. Meanwhile, industrial systems in high-income countries prioritize efficiency, but this approach often contributes to environmental degradation and social inequalities. ASFs are important sources of protein, iron, and vitamin B12. They can address malnutrition and provide income for women in low- and middle-income countries. However, rising demand for meat and dairy, as well as climate pressures, threaten system stability. Livestock generates 14.5% of greenhouse gas emissions and requires a substantial amount of land and water, underscoring the need for solutions now. Precision farming, new varieties genetically modified to resist drought, and other strategic innovations could help, but they need supportive policies and handsome investments. A collaborative approach is essential to balancing the benefits of livestock with environmental constraints. Policymakers should prioritize climate-smart subsidies and carbon pricing. Researchers must develop sustainable metrics, and consumers in high-income countries should shift towards consuming less but higher-quality meat. Future research should focus on climate-resilient livestock systems, equitable access to technology, and integrated health strategies. As Livestock remains vital for food security, success depends on merging traditional knowledge with modern science while ensuring equity in food policies for future generations.

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