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Gender Disparity, Digital Inequality, and Climate Resilience: Impacts on Food Security in Smallholder Livestock Based Livelihoods in Sub-Saharan Africa

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Abstract

The intersection of gender, digital equity, and climate resilience plays a critical role in the sustainability and productivity of smallholder livestock systems. This, in turn, contributes to sustained nutrition and food security, thereby shaping rural development and economic growth across sub-Saharan Africa. Gender constitutes a crucial socioeconomic factor in examining disparities in smallholder livestock livelihoods, including aspects such as nutrition and food security, as well as the capacities for adaptation, vulnerabilities, and resilience to climate change within local communities. Furthermore, gender inequality and digital marginalization pose significant threats to the sustainability and productivity of rural agrarian economies. Digital tools and services have the potential to enhance smallholder livestock productivity, improve market access, and strengthen household nutrition and food security. However, gender disparity in livestock farming, digital inequality, and climate vulnerability have limited the benefits of digitalization in smallholder livestock systems, particularly for women farmers who are primary livestock caretakers. This review synthesizes empirical evidence on the intersection of digital exclusion and gender inequality in livestock systems and proposes a conceptual framework linking digital access, capability, and empowerment to livestock and nutrition outcomes. Findings highlight that interventions addressing both technology and gender barriers can improve household dietary security and diversity, income, and resilience. The study underscores the need for gender-responsive, nutrition-sensitive digital strategies to enhance livestock-based livelihoods and food security in SSA. In conclusion digital inclusion, when paired with gender-responsive empowerment, enables women livestock keepers in Sub-Saharan Africa to boost productivity, nutrition, and resilient rural livelihoods.

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Keywords: Gender disparity, Digital marginalization, Livestock, Food security, Nutrition, Smallholder farmers, Sub-Saharan Africa

1. Introduction

The intersection of gender disparities, digital inequities, and climate resilience critically influences the sustainability and productivity of smallholder livestock systems, thereby shaping rural development and economic growth across sub-Saharan Africa (Larson *et al.*, 2020). The region must prioritize sustainability through digital tools and gender-sensitive climate strategies aligned with the 2030 Agenda (Abraham & Pingali, 2020). As the dominant sector, smallholder agriculture produces 70–80% of global food (Ricciardi *et al.*, 2021) and drives rural economies (Larson *et al.*, 2020). This sector ensures food security,

nutrition, income generation, and community resilience (WIEGO, 2017; World Bank, 2015b; Wiggins & Keats, 2013; von Braun, 2005). Smallholder livestock farming provides subsistence and contributes to rural development (Bolang *et al.*, 2023; File and Nhamo, 2023; UN, 2015). These livestock systems generate household income, dietary diversity, and resilience to climatic and economic shocks. They preserve indigenous animal genetic resources and provide essential animal-source foods for human health (HLPE, 2016; Leroy *et al.*, 2022)^[20]. However, these systems remain vulnerable to climate change due to limited resources and weak institutional support (Thornton *et al.*, 2021; IPCC, 2022)^[26].

In smallholder livestock systems, women play a vital role, primarily accountable for the routine management of animals, with a particular focus on small ruminants, poultry, and dairy production. Within these systems, women predominantly act as the main caregivers and managers of livestock, especially in the domains of small ruminant and poultry production (FAO, 2019; Njuki & Sanginga, 2018)^[22]. Evidence indicates that while women may not always own livestock assets, they contribute a substantial share of the labor in livestock husbandry, including feeding, watering, health care, and processing of animal products (Njuki & Sanginga, 2018; FAO, 2023)^[22]. In many smallholder contexts, women are estimated to provide over 50% of the labor in livestock-related activities, with even higher involvement in poultry and small stock systems that are critical for household nutrition and income (ILRI, 2019; Quisumbing *et al.*, 2019)^[25]. Livestock-derived foods such as milk, eggs, and meat are essential sources of high-quality protein and micronutrients, and women's control over these resources is strongly associated with improved household dietary diversity and child nutrition outcomes (Leroy *et al.*, 2022)^[20].

Gender serves as a pivotal socioeconomic variable in the analysis of differential smallholder livestock livelihoods, digital technology adoption, as well as adaptation capacities, vulnerabilities, and resilience to climate change in rural communities in sub-Saharan Africa (Baylie, 2025; (Aryal *et al* 2022; Afridi *et al* 2021; Ampaire *et al* 2020)^[5, 4, 1, 3]. Assan, 2014). Gendered digital marginalization has far-reaching implications for livestock productivity, household income, and nutritional outcomes. Socio-cultural norms limited digital literacy, and restricted control over productive resources continue to hinder women's effective use of digital innovations, despite their critical role in livestock production (Quisumbing *et al.*, 2019; FAO, 2019)^[25]. Yet digital tools—such as mobile-based extension services, climate advisory platforms, and digital market systems—offer considerable potential to enhance decision-making, improve market participation, and support nutrition-sensitive livestock production.

For livestock development interventions—particularly the digitization of smallholder livestock systems—to achieve meaningful and sustained impact, they must be explicitly gender-responsive. In Sub-Saharan Africa, smallholder systems constitute a substantial share of the livestock population, with women playing a central role in daily animal husbandry and management. Despite this, their contributions remain undervalued and inadequately supported, while persistent structural barriers—including limited access to land, credit, extension services, and emerging digital technologies—continue to reinforce gender inequalities and

constrain productivity gains (Doss *et al.*, 2018; FAO, 2023; Kansiime *et al.*, 2022; World Bank, 2021)^[6, 7, 18]. These constraints are further intensified by climate-related stressors, which disproportionately affect resource-poor and marginalized groups, particularly women. Consequently, the intersection of gender disparity, digital inequality, and limited adaptive capacity poses a significant risk to the sustainability of food security in smallholder livestock systems.

This review synthesizes existing evidence on the nexus between gender inequality and digital exclusion in livestock-based livelihoods, highlighting key pathways through which these dynamics influence food security. It further proposes a conceptual framework linking digital access, capabilities, and empowerment to improved livestock productivity, income generation, and dietary outcomes, while identifying strategic intervention points, including gender-responsive digital design, targeted capacity building, and inclusive policy support. Addressing these interconnected challenges is essential for fostering equitable, climate-resilient, and nutrition-sensitive livestock systems that enable both women and men to fully benefit from the opportunities presented by digital agriculture.

2. Systematic Review Methodology

This study employed a systematic review methodology guided by the PRISMA framework to ensure transparency, reproducibility, and methodological rigor. A comprehensive literature search was conducted across multiple databases, including Scopus, Web of Science, Google Scholar, PubMed, and FAO databases, to capture a wide range of peer-reviewed and grey literature relevant to the research focus. The search strategy utilized carefully constructed Boolean keyword combinations such as “gender inequality” AND livestock, “digital agriculture” AND smallholder farmers, “climate resilience” AND livestock systems, “food security” AND Sub-Saharan Africa, and “digital gender gap” AND agriculture, ensuring broad yet targeted coverage of interdisciplinary themes.

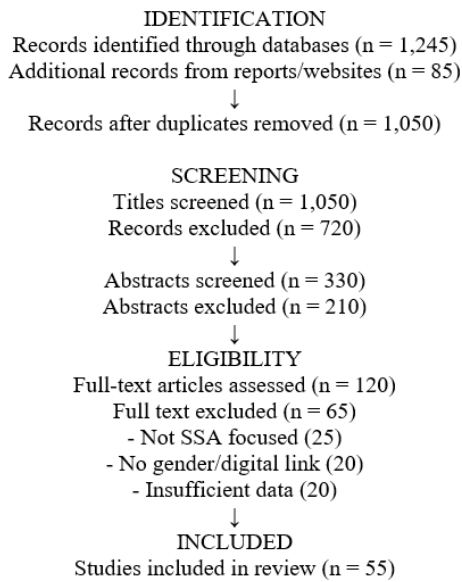
Studies were included if they were published between 2010 and 2025, focused on Sub-Saharan Africa, and addressed at least two of the following domains: gender, digital access, and livestock or food security. Eligible sources comprised peer-reviewed journal articles, institutional reports, and working papers. Conversely, studies were excluded if they were non-English publications, lacked empirical or conceptual relevance, focused solely on technical ICT aspects without linkage to agriculture, or were duplicate records.

The screening process involved exporting all identified studies into a reference management system, followed by systematic removal of duplicates. A three-stage screening procedure was then applied, beginning with title screening, followed by abstract screening, and finally full-text eligibility assessment to ensure alignment with the study objectives. Data extraction focused on key variables including study location, type of livestock system, gender dimensions examined, digital tools employed, and reported outcomes such as productivity, nutrition, and resilience.

To ensure the credibility and robustness of the review, a quality assessment of selected studies was conducted based on methodological rigor, adequacy of sample size, strength of analytical approach, and relevance to the integrated nexus framework. Finally, a thematic synthesis approach was

applied to analyse the data, enabling the identification of recurring patterns and relationships, including digital marginalization trends, gendered constraints in access to resources and technologies, pathways to climate resilience, and nutrition-sensitive outcomes within livestock systems.

Prisma flow diagram



3. Results

3.1. Analytical Framework: Linking Gender, Digital Access, and Smallholder Livestock Farming Outcomes

The link between gender inequality, lack of digital access, and climate resilience affects how sustainable and productive small farms with livestock are in Sub-Saharan Africa. Figure 1 depicts the pathways through which digital marginalization and gender disparity influence livestock productivity and food security outcomes in Sub-Saharan Africa (SSA). The framework conceptualizes digital marginalization (red) as limited access to digital infrastructure, such as mobile phones, reliable Internet connectivity, and online livestock extension services, which can restrict information flow, market access, and the adoption of productivity-enhancing innovations (Aker, 2011; Abubakar *et al.*, 2021). Research indicates that although mobile phone ownership in SSA has surged, disparities in gender, geography, and education levels continue to hinder equitable participation in digital agriculture (GSMA, 2020). These structural gaps in digital

inclusion worsen existing production inefficiencies and restrict farmers' capacity to respond to climate and market signals that affect nutritional outcomes (Meijer *et al.*, 2019). Figure 1 illustrates the direct effects, such as digital access facilitating the receipt of livestock extension messages, whereas dashed arrows denote mediated or feedback relationships, such as empowerment affecting the effective utilization of information and reinvestment into productive assets. The framework emphasizes that interventions should integrate investments in digital infrastructure with gender-responsive training, resource access, and empowerment strategies to fully leverage the potential of digital technologies for nutrition-sensitive and equitable livestock systems (FAO, 2019; World Bank, 2021).

Persistent gender disparities hinder women's access to livestock assets, financial services, and decision-making authority, thereby limiting their capacity to adopt innovative and climate-smart practices. Concurrently, digital inequalities—evident through restricted access to mobile technologies, information platforms, and agricultural advisories—further impede timely access to weather forecasts, market information, and livestock health guidance. These intersecting inequities undermine adaptive capacity, diminishing household resilience to climate shocks, such as droughts, floods, and disease outbreaks, ultimately jeopardizing both livestock-based livelihoods and food security. Addressing this nexus necessitates integrated interventions that empower women, bridge digital divides, and strengthen climate-resilient livestock practices, thereby enhancing productivity, nutritional outcomes, and the long-term sustainability of smallholder food systems.

Gender disparity in the framework captures socio-cultural norms, restricted ownership of key productive assets (including land and livestock), and limited decision-making power that disproportionately affect women livestock keepers. Empirical evidence indicates that women in rural SSA often have less control over household resources and incomes, lower rates of literacy and digital skills, and reduced participation in formal livestock value chains compared with men (Doss, 2018; FAO, 2019) [6, 7]. These gendered constraints interact with digital exclusion: for example, women may have access to a mobile phone but lack the autonomy to use it for agriculture-related services or financial transactions (Quisumbing *et al.*, 2019) [25]. Consequently, digital tools designed without attention to gender dynamics risk reinforcing existing inequities rather than alleviating them.

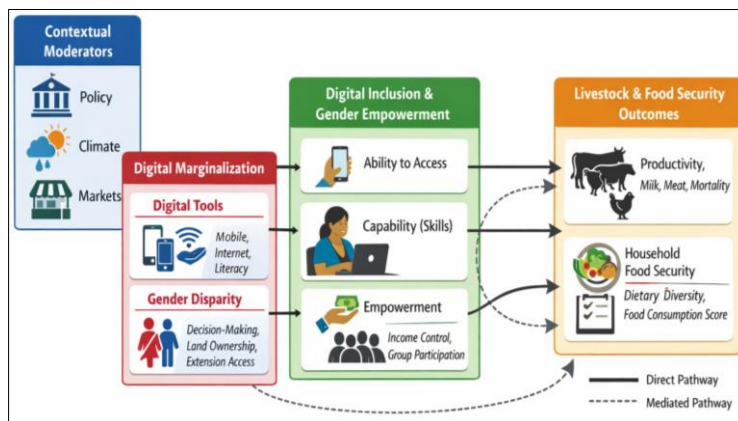


Fig 1: Conceptual Framework Linking Digital Inclusion, Gender Empowerment, and Livestock-Based Food Security Outcomes under Contextual Moderators

The framework's mediating mechanisms consist of (a) access—the provision of digital devices, connectivity, and locally pertinent livestock information; (b) capability—the proficiency and assurance necessary to effectively employ digital tools; and (c) empowerment—the capacity to make informed decisions concerning livestock management and household nutrition (Van Deursen & Van Dijk, 2014; Heeks, 2020). These mechanisms are pivotal in determining whether digital technologies result in improved livestock practices, such as prompt animal healthcare, optimized feeding strategies, and informed breeding choices, which subsequently influence livestock productivity and household food security (Murphy *et al.*, 2018). Ultimately, the outcomes related to livestock and food security (green) signify enhancements in productivity, expanded market engagement, and superior dietary quality—particularly the intake of animal-derived foods that are vital for child development and micronutrient adequacy (Neumann *et al.*, 2002; Tontisirin *et al.*, 2002).

3.2. Digital Marginalization in Smallholder Livestock Systems

Digital technologies, including mobile phones, online extension platforms, and livestock management applications, have the potential to transform smallholder livestock systems by enhancing productivity, improving access to veterinary services, and facilitating market participation (Aker & Mbiti, 2010; Fifield *et al.*, 2022)^[2, 11]. Timely information on animal health, breeding, feed management, and market prices can increase livestock output and reduce post-harvest losses. In addition, digital financial services, such as mobile banking, e-wallets, and livestock insurance, provide smallholders with access to credit and savings mechanisms tailored to livestock-based livelihoods. When effectively adopted, these innovations can strengthen resilience to climate shocks by enabling proactive decision-making, diversification of income streams, and responsiveness to market opportunities (World Bank, 2020; Baylie, 2025)^[5].

Despite these potential benefits, smallholder livestock producers in sub-Saharan Africa face persistent digital marginalization due to structural and socio-economic barriers. Rural network coverage is often limited or unreliable, reducing consistent access to online services, while low digital literacy constrains effective technology use (Fifield *et al.*, 2022; World Bank, 2020)^[11]. The high cost of mobile devices, data plans, and electricity access further limits adoption among resource-poor households, disproportionately affecting women, youth, and marginalized communities. Consequently, many smallholders continue to rely on informal knowledge networks, local extension visits, or peer-to-peer communication, which are slower and often less accurate. This digital divide restricts opportunities for productivity gains and exacerbates inequalities in income, market access, and climate resilience, highlighting the need for targeted interventions to improve digital inclusion in livestock systems.

Moreover, digital marginalization intersects with gender disparities, shaping livestock outcomes and resilience pathways. Women, who predominantly manage poultry, goats, and small ruminants, often have lower access to mobile devices, internet connectivity, and digital literacy programs than men (Baylie, 2025; Njuki *et al.*, 2011)^[5, 22]. Limited access to climate forecasts, veterinary advice, and market information reduces their adaptive capacity to climate

variability and shocks, negatively affecting productivity, income, and household nutrition outcomes. Addressing these gaps through gender-responsive digital interventions—such as affordable mobile solutions, women-centered e-extension services, and targeted training—can enhance both climate resilience and economic empowerment, creating more equitable and sustainable smallholder livestock systems across sub-Saharan Africa (Herforth & Ahmed, 2015; Njuki *et al.*, 2011)^[22].

3.3. Gender Disparities in Digital Access in Smallholder Livestock Systems

Gender-responsive digital design is not merely desirable; it is essential for smallholder livestock production. Gender disparities in digitalization within smallholder livestock farming often exacerbate existing gender inequalities, resulting in a "digital gender gap," in which women encounter greater barriers to access and adoption than men. Digital tools developed for animal production advisory services are rapidly transforming smallholder livestock systems across Sub-Saharan Africa by providing real-time weather updates, pest and disease alerts, and tailored smart animal husbandry advice. However, without careful design, these tools can exacerbate persistent gender-based disparities in smallholder livestock-based livelihoods in Sub-Saharan Africa. Women are disproportionately affected by digital exclusion due to socio-cultural norms, restricted mobility, lower literacy, and limited control over resources (Doss, 2018; FAO, 2019)^[6, 7]. Empirical studies in Uganda, Kenya, and Ethiopia have demonstrated that women's digital marginalization restricts livestock productivity and income, even when men have access to similar technologies (Kikulwe *et al.*, 2014; Njuki & Sanginga, 2013)^[19, 22].

Gender inequalities in digital access within smallholder livestock systems are often intensified when women encounter limited access to production inputs, digital technologies, and decision-making spaces, largely due to prevailing social norms, inequitable ownership rights, and constrained access to credit (Kansiime *et al.*, 2022; ICT Works, 2024)^[18]. The digital gender gap has been exacerbated by entrenched socio-cultural norms, unequal access to digital technologies, gender-biased digital literacy, and the burden of unpaid care work, leading to time scarcity, all of which limit women's ability to benefit from livestock advisory and extension tools, thereby reinforcing male dominance in the sector. It has been observed that digital access in smallholder livestock systems often mirrors the biases inherent in traditional extension services, where male farmers tend to dominate interactions unless interventions are intentionally designed to effectively include and reach women (Jarial & Sachan, 2021; Kansiime *et al.*, 2022)^[17, 18]. Addressing gender disparities in digitization within smallholder livestock systems requires a gender-responsive approach that expands women's access to digital livestock technologies, strengthens their digital literacy, and ensures that agro-advisory and extension platforms are intentionally designed to meet women's needs and constraints.

3.4. Key Mediating Pathways: Digital Access, Capacity, and Empowerment

This framework highlights that the beneficial effects of digital inclusion depend on three pivotal mediating mechanisms: access, capability, and empowerment. Access involves having the requisite devices and dependable Internet

connectivity, which serves as the fundamental infrastructure necessary for engaging in digital environments. Without this foundational access, individuals or communities are unable to harness digital tools or platforms effectively. Capability refers to the digital literacy and technical competencies necessary for the effective navigation, interpretation, and utilization of digital resources. This encompasses not only fundamental operational skills but also the capacity to critically engage with digital content and services. Empowerment pertains to possessing the authority and autonomy to make informed decisions regarding resource allocation, livestock management, and innovation adoption. This mechanism ensures that users can convert their access and skills into meaningful actions that lead to tangible improvements.

Empirical evidence indicates that interventions targeting all three mechanisms together result in substantial improvements in livestock management, market participation, and household nutrition, as shown by Grace *et al.* (2018)^[13] and Herrero *et al.* (2017)^[14]. Conversely, programs that neglect gender disparities or fail to close skill gaps risk reinforcing existing inequalities, as marginalized groups remain excluded from the full advantages of digital inclusion. To use digital technologies for fair and lasting development, we need strong plans. These plans should include building infrastructure, teaching skills, and empowering people, especially those who are vulnerable.

3.5. Outcomes for Livestock Productivity and Household Food Security

Enhanced digital access, improved capabilities, and empowerment of women collectively bolster the efficiency of livestock management, disease surveillance, and market participation. Access to timely and pertinent digital information empowers farmers to adopt enhanced husbandry practices, respond swiftly to disease outbreaks, and optimize feeding and breeding strategies. These advancements have led to increased livestock productivity and greater availability of animal-sourced foods, which are essential for improving household dietary diversity, particularly among children and women of reproductive age (Herrero *et al.*, 2021; Herrero *et al.*, 2017)^[14].

The framework further emphasizes that food security outcomes are not solely reliant on increased production but also on equitable access to resources, information, and decision-making power within households. Digital tools facilitate informed and timely decision-making, enabling livestock keepers to allocate resources efficiently and mitigate the risks associated with climate variability, disease outbreaks, and market fluctuations. This is particularly crucial in smallholder systems, where vulnerability to shocks is high.

By harnessing the power of digital platforms, farmers are not only accessing real-time price information and broader markets but are also revolutionizing their economic landscape. This transformation empowers them with unprecedented bargaining power and income stability, directly enhancing household resilience. The economic benefits are undeniable, paving the way for sustained investments in livestock production. This holistic approach, which seamlessly integrates digital inclusion, empowerment, and market access, is not merely beneficial; it is essential for cultivating sustainable livestock systems. These systems are pivotal in advancing nutritional outcomes and securing

livelihoods, making this strategy an indispensable catalyst for progress.

3.6. Gender-Responsive Policy and Program Strategies

To develop effective interventions, it is imperative to consider the broader sociocultural dynamics that shape women's involvement in livestock systems. This requires addressing gender norms and power dynamics that often constrain women's mobility, access to resources, and participation in decision-making processes. Community engagement strategies tailored to specific contexts and gender-sensitive communication approaches can help transform these norms by involving men and other key stakeholders in supporting women's empowerment. Furthermore, designing digital platforms and advisory services with input from women livestock keepers ensures that the content is relevant, accessible, and responsive to their unique needs and challenges, thereby encouraging greater adoption and sustained use.

In addition, reinforcing institutional support mechanisms is vital for maintaining the benefits of digital interventions. This entails fostering partnerships among government agencies, non-governmental organizations, private sector actors, and local communities to create an enabling environment for women's participation in livestock value chains. Financial inclusion initiatives, such as microcredit, savings groups, and insurance products tailored for women, can bolster their economic resilience and capacity to invest in improved livestock management practices. By integrating climate-smart approaches and market linkages within these frameworks, women can be further empowered to adapt to environmental changes and seize emerging economic opportunities, ultimately contributing to more equitable and sustainable livestock systems.

4. Discussion

This review underscores the complex interplay between digital exclusion and gender inequality in livestock-based livelihoods, demonstrating that simply providing access to digital tools is not enough to achieve equitable outcomes. Digital inclusion must be paired with targeted capacity-building, gender-responsive programming, and supportive policies to meaningfully address the structural barriers that women livestock keepers face. Recent literature on digital agriculture highlights persistent challenges in digital infrastructure, affordability, and digital literacy, which disproportionately affect women and other marginalized groups in low- and middle-income countries (LMICs) and smallholder contexts, thereby limiting the potential benefits of digital platforms for productivity and market access (Manzoor *et al.*, 2025; Gumbi *et al.*, 2023).

Empirical evidence increasingly suggests that gender-responsive digital interventions—those designed with an explicit understanding of women's roles, constraints, and needs—can lead to measurable improvements in agricultural outcomes, nutrition, and empowerment. For example, studies of urban and peri-urban female farmers show that digital tools that enhance access to real-time market information, financial services, and training can strengthen economic resilience, decision-making capacity, and participation in value chains when complemented by efforts to overcome socioeconomic and cultural barriers (Yousif *et al.*, 2025). However, the literature also emphasizes that without intentional design that tackles gender norms, literacy gaps, and control over

resources, digital interventions risk replicating existing inequalities or providing benefits that remain inaccessible to women due to systemic exclusion (Alliance Bioversity CGIAR)

For future research there is a clear need for longitudinal and multi-country research to robustly quantify the long-term economic, nutritional, and gender-equity impacts of digital livestock interventions. Such studies should integrate mixed methods to capture not only adoption and productivity metrics but also nuanced shifts in decision-making, time use, and intra-household power dynamics—outcomes that are central to women’s empowerment but often overlooked in short-term evaluations. Additionally, research should systematically assess context-specific barriers such as sociocultural norms, digital literacy levels, infrastructure gaps, and market dynamics to design scalable, sustainable, and gender-transformative strategies that truly benefit women livestock producers. Bridging these evidence gaps will be crucial for policymakers and development practitioners seeking to leverage digital technologies for more inclusive livestock systems.

5. Conclusion

The advancement of gender-sensitive digital tools and services presents a significant opportunity to transform smallholder livestock-based livelihoods by enhancing productivity and improving household food security in Sub-Saharan Africa. However, the success of these initiatives depends on addressing persistent gender disparities that limit women's access to digital tools, information, and decision-making power in smallholder farming sector, thereby perpetuating food insecurity in rural agrarian economies. Without intentional efforts to bridge these gaps, digital innovations risk reinforcing existing gender inequalities rather than providing inclusive benefits for smallholder livestock development. To achieve equitable and sustainable food security outcomes, agricultural policies and development interventions for smallholder livestock must integrate digital access with capacity building, gender-responsive design, and empowerment strategies. Empowering women livestock keepers to effectively utilize digital technologies can boost productivity, strengthen resilience to climate shocks, and improve household nutrition, ultimately contributing to more inclusive and sustainable rural livelihoods. In conclusion, digital inclusion, when combined with gender-responsive empowerment, enables women livestock keepers in Sub-Saharan Africa to enhance productivity, nutrition, and resilient rural livelihoods.

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