Genetic Resilience in Indigenous Chickens: A Strategic Animal Genetic Resource for Climate-Smart Smallholder Poultry Systems in Sub-Saharan Africa.

Never Assan

Zimbabwe Open University, Faculty of Agriculture, Department of Agriculture Management Bulawayo Regional Campus, Bulawayo, Zimbabwe.

DOI: https://dx.doi.org/10.51584/IJRIAS.2025.10120080

Received: 14 August 2025; Accepted: 19 August 2025; Published: 17 January 2026

ABSTRACT

In Sub-Saharan Africa, the smallholder agricultural sector harbors a rich genetic repository of indigenous village chicken ecotypes, which are vital to rural livelihoods in different agroecological regions. Despite being highly exposed to the adverse effects of climate change, including temperature extremes, shifting disease patterns, and resource scarcity, these local genetic resources have consistently demonstrated remarkable resilience. Their innate adaptability to harsh and fluctuating agroecological conditions positions them as a strategic asset for climate-resilient agriculture, offering clear advantages over imported breeds that often lack such environmental robustness. The intensification of climatic fluctuations—exhibited through reduced water availability, erratic precipitation patterns, rising ambient temperatures, unpredictable seasonal cycles, diminishing feed sources, and the proliferation of novel pathogens and parasites—has severely disrupted traditional poultry production systems. Nevertheless, certain indigenous chicken phenotypes, such as the naked neck variety, exhibit considerable resilience owing to their unique physiological, behavioral, and morphological adaptations to challenging environments. This review emphasizes the critical need to identify, develop, and promote these resilient subpopulations through intra-population selection and proactive, community-oriented breeding initiatives. By merging climate-smart breeding technologies with indigenous knowledge systems, both the productivity and survivability of village chickens can be significantly enhanced. Facilitating the proliferation of these climate-adapted genetic resources is central to reinforcing rural household resilience, securing food and nutritional stability, and sustaining livelihoods amid growing climatic adversities. The review advocates for the urgent transformation of poultry systems by mainstreaming resilient indigenous chicken ecotypes into adaptive strategies for climate-resilient agriculture.

Keywords: Indigenous village chickens, Genetic diversity, Climate change impacts Climate resilience, Livelihood, Smallholder agriculture, Sub-Saharan Africa

INTRODUCTION

The escalating manifestations of climate change—characterized by rising ambient temperatures, prolonged and more frequent drought episodes, heightened variability in precipitation regimes, and the emergence and resurgence of novel pathogenic threats—pose profound challenges to the resilience, sustainability, and productivity of livestock production systems across Sub-Saharan Africa (SSA) (Thornton et al., 2021; FAO, 2021). These shifts are not only undermining the ecological balance of pastoral and agro-pastoral landscapes but are also exacerbating resource scarcity, particularly for water, forage, and animal health services (Maina et al., 2020).

Smallholder farmers, who form the backbone of agricultural production in the region, are disproportionately affected due to their reliance on low-input, mixed crop-livestock systems that lack the technological buffers and adaptive infrastructure necessary to withstand climate variability (Opio et al., 2021). Consequently, production losses, animal morbidity and mortality, and nutritional insecurity are becoming more pronounced. Within this increasingly fragile context, indigenous livestock resources—especially village chickens—are gaining renewed attention as pivotal assets for building agricultural resilience. These chickens, shaped by generations of natural selection and local adaptation, possess a unique combination of traits that enable them to survive and reproduce under marginal and fluctuating environmental conditions (Gwala et al., 2022). Their resilience to heat stress, ability to scavenge in resource-poor environments, and resistance to locally prevalent diseases make them indispensable for sustaining livelihoods, ensuring food and nutrition security, and enhancing the adaptive capacity of rural households facing the brunt of climate change (Akinola et al., 2021; FAO, 2021).

Village chickens, often referred to as indigenous chickens, serve as a cornerstone of livelihood strategies among smallholder farmers in Sub-Saharan Africa (SSA), owing to their intrinsic resilience to climate-induced environmental stressors (Akinola et al., 2021). Their genetic adaptability to heat stress, fluctuating precipitation patterns, emerging diseases, and degraded landscapes renders them critical assets for sustaining food and nutritional security under escalating climate variability and long-term climatic shifts (FAO, 2021a). These birds provide essential sources of protein, income, and cultural value, particularly in remote and low-resource settings. Their extensive genetic variability, resistance to endemic diseases, and capacity to perform under minimal-input conditions render them exceptionally compatible with the agro-ecological and socio-economic realities of rural SSA (Thornton et al., 2021). Despite their limited inclusion in formal commercial poultry systems, indigenous chickens constitute a substantial proportion of the region's poultry population and are increasingly recognized for their critical role in safeguarding food security and sustaining rural livelihoods amid intensifying environmental and economic volatility (Akinola et al., 2021; Mtileni et al., 2020; Yakubu, 2022).

These chickens occupy a strategically important role in regional initiatives aimed at enhancing nutritional security, economic resilience, and climate adaptation (FAO, 2021b; Maina et al., 2020). Their natural ability to thrive in environmentally challenging, low-resource settings makes them a cornerstone of subsistence agriculture in climate-stressed zones. However, the growing frequency and severity of climate-related stressors—such as prolonged drought, unpredictable rainfall patterns, increasing temperatures, and the emergence of novel diseases—pose serious threats to their productivity and survival. These risks are exacerbated by the limited availability of adaptive technologies, veterinary support, and infrastructural investment accessible to smallholder farmers (Opio et al., 2021; Akinola et al., 2021). Evidence from recent research underscores the importance of targeted efforts to strengthen and promote indigenous poultry systems as a means of bolstering the adaptive capacity of rural agriculture in the face of climate change (FAO, 2021).

There is growing scholarly and practical interest in exploiting the adaptive capacities of specific indigenous chicken phenotypes—such as the naked neck, frizzled, and dwarf varieties—which exhibit enhanced tolerance to heat stress, limited feed availability, and prevalent diseases. These traits contribute to improved thermoregulation, efficient feed conversion, and increased survival rates in marginal environments, making these chickens ideal candidates for climate-resilient breeding initiatives (Gwala et al., 2022). Integrating such adaptive characteristics into dual-purpose breeding objectives can simultaneously enhance productivity and environmental resilience, particularly in arid and semi-arid regions where exotic breeds often falter. Contemporary research advocates for selective breeding programs that incorporate both adaptive and performance traits, as this integrated approach is pivotal to establishing sustainable, smallholder-centric poultry production systems capable of withstanding climatic pressures (Thornton et al., 2021; Yusuf et al., 2021).

For genetic improvement strategies of indigenous chicken resources to achieve lasting impact, they must be embedded within robust institutional frameworks that recognize and integrate the complex socio-cultural, economic, and gender dynamics shaping rural African poultry systems. This involves equitable access to agricultural extension services, incorporating local knowledge into scientific frameworks, and strengthening market linkages for rural producers to engage in value chains (FAO, 2021a). Participatory village chicken breeding methodologies, with inclusive policies, are crucial for preserving the nutritional, economic, and adaptive functions of indigenous poultry for vulnerable populations. This review calls for a paradigm shift in poultry development, promoting resilient indigenous ecotypes. It synthesizes climate-induced constraints affecting village chicken systems, identifies critical adaptive traits, and outlines strategic interventions Including within-population selection, community-based breeding, and policy harmonization, to drive sustainable genetic progress. By addressing productivity and resilience, indigenous chickens can be transformative agents in building robust, climate-adaptive agricultural systems across Sub-Saharan Africa.

METHODOLOGY

This review followed the PRISMA 2020 guidelines to ensure methodological rigor and reproducibility of the results. This study aimed to gather data on the adaptation, genetic enhancement, and climate resilience of native village chickens in sub-Saharan Africa. An extensive search was performed across various databases, such as Web of Science and Google Scholar, for studies published between January 2000 and April 2025, with a particular focus on the recent literature from 2015 to 2025. The search strategy included terms related to native chickens, climate adaptation, and improvement strategies, specifically targeting Sub-Saharan Africa.

The inclusion criteria included peer-reviewed articles, reports, and theses on native chickens and climate adaptation, while studies on non-native breeds or those conducted outside the region were excluded. All records were systematically organized using Zotero, and duplicates were eliminated. Titles and abstracts were screened for relevance, followed by a full-text review, and additional sources were identified from reference lists. Two reviewers independently selected the studies and resolved any discrepancies through discussion.

Data extraction was performed using a standardized template that captured the study details, chicken traits, breeding strategies, and key findings. The results were categorized into four thematic areas: adaptive traits, breeding strategies, community breeding outcomes, and molecular and genomic advances. The methodological quality was assessed using a modified version of the CASP checklist. Of the 412 records initially identified, 146 studies met the inclusion criteria, providing strong evidence of the contribution of native village chickens to climate-smart poultry systems.

RESULTS AND DISCUSSION

A Framework for Climate-Resilient Indigenous Chicken Production to Strengthen Smallholder Livelihoods

Figure 1 presents a conceptual diagram illustrating the Climate-Resilient Indigenous Chicken Improvement Framework for the smallholder farming sector, aimed at enhancing livelihood and resilience. This framework delineates the interconnected pathways through which indigenous chicken genetic resources support climate-resilient smallholder poultry systems in Sub-Saharan Africa. At the apex of the diagram, climate change factors—such as heat stress, drought, and shifting disease patterns—pose environmental challenges that affect poultry productivity and survival. Indigenous chicken ecotypes, including naked neck, frizzle, and dwarf types, constitute the genetic basis for adaptation within these systems. Climate change influences indigenous chicken production through multiple interconnected drivers.

Key climate drivers encompass rising temperatures, altered rainfall patterns, extreme weather events, and increased prevalence of disease vectors. These environmental stressors disrupt the natural equilibrium of smallholder farming systems, creating conditions that are often detrimental to poultry survival and productivity. Consequently, production impacts become apparent. Indigenous chickens experience heat stress, which can diminish growth rates, egg production, and overall flock performance. Limited feed and water availability further restrict productivity, while nutritional stress often results in altered reproduction, including decreased egg laying and hatchability. Additionally, changing climatic conditions facilitate the emergence and resurgence of poultry diseases, as well as increased parasite burdens, further threatening flock health and farm livelihoods. To address these challenges, farmers and researchers have developed various adaptive responses.

A key strategy is the selective breeding of climate-resilient ecotypes, favoring chickens that can tolerate heat, resist local diseases, and maintain productivity under fluctuating environmental conditions. Improvements in housing—such as well-ventilated, shaded, and insulated structures—help mitigate heat stress and reduce exposure to extreme weather. Feed innovations, including supplementation with locally available or drought-tolerant feed resources, ensure adequate nutrition even during periods of scarcity.

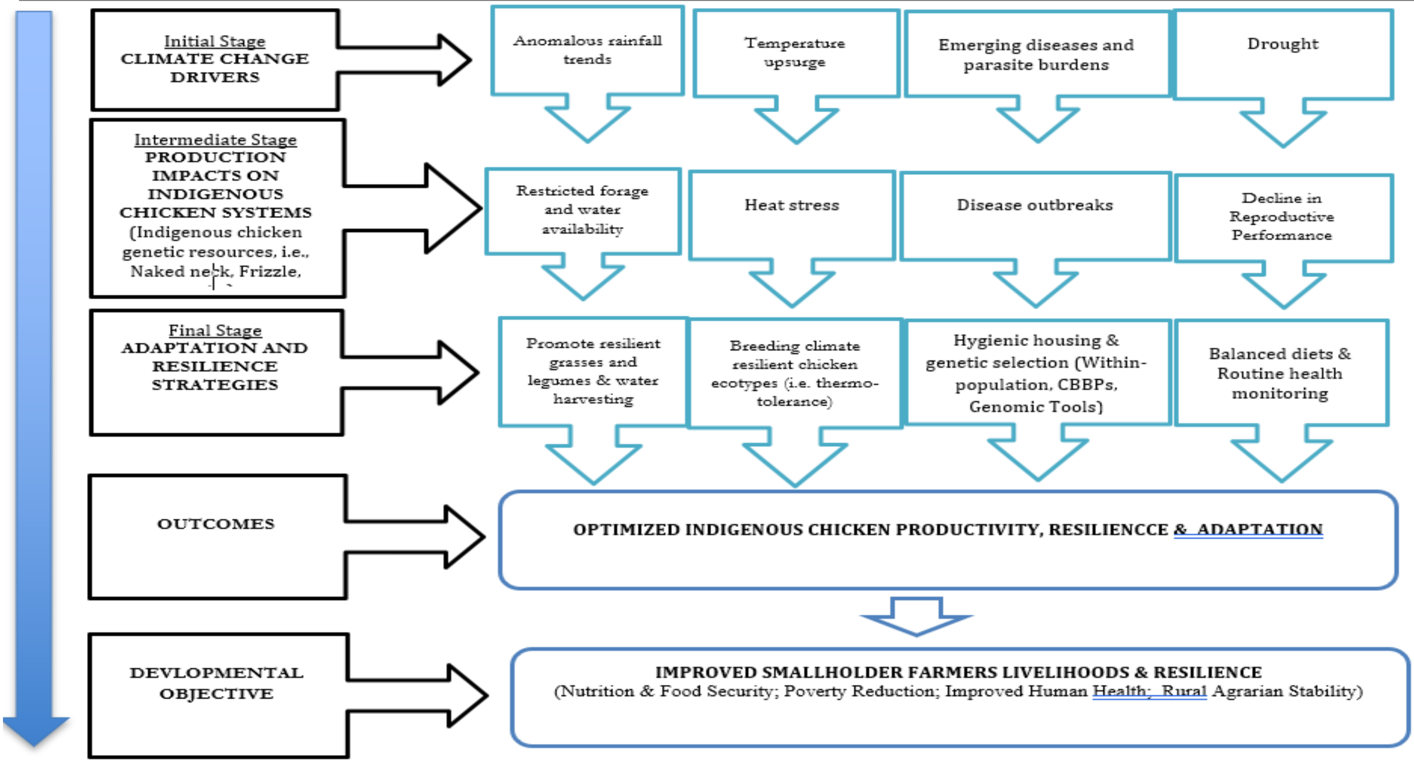

Figure 1. Conceptual Diagram – Climate-Resilient Indigenous Chicken Improvement Framework for the Smallholder farming sector to Improve Livelihood and Resilience

Finally, health interventions, such as vaccination programs, biosecurity measures, and parasite control, enhance the overall resilience of indigenous chicken populations, enabling smallholder farmers to sustain productivity despite the challenges posed by a changing climate. Table 1 provides a detailed examination of indigenous chicken ecotypes throughout Sub-Saharan Africa, emphasizing their geographical distribution, key adaptive and productive characteristics, and pertinent literature sources.

Ecotype/Variety	Location	Phenotypic & Adaptive Traits	Sources
Naked Neck (Na)	Ethiopia, Uganda, Tanzania, Nigeria, Zimbabwe, Egypt	Reduced feather coverage (20–40%); superior heat dissipation; higher expression of HSP70 & HSP90; good scavenging ability; moderate egg yield under heat stress.	Guni et al., 2020; El-Tarabany et al., 2021; Ahmed et al., 2020; Banda et al., 2021; Khalil et al., 2022; Chikumba et al., 2025
Frizzle (F)	Nigeria, Ghana, Benin, Tanzania, Malawi	Curled feathers improve air circulation; better heat tolerance than normal-feathered; moderate growth rate; attractive plumage for cultural uses.	Banda et al., 2021; Yakubu et al., 2021b; Ngeno et al., 2021
Dwarf	Ethiopia, Nigeria, Ghana	Small body frame reduces feed and water requirements; hardy in scavenging systems; broodiness is maintained; lower metabolic heat output.	Aklilu et al., 2023; Mtileni et al., 2020; Yakubu et al., 2021c
Kuchi	Tanzania	Large body size; aggressive temperament; high meat yield; adapted to free-range; valued for cultural uses in ceremonies.	Mpenda et al., 2019; Muchadeyi et al., 2020

Koekoek (cross)	South Africa, Namibia	Dual-purpose (meat and eggs); better egg production; higher body weight; some adaptation to rural conditions, but less hardy than pure indigenous.	Maluleke & Mokwena, 2025; Okeno et al., 2020
Fulani	Nigeria	Tall, long-legged; adapted to arid zones; high foraging ability; tolerant to Newcastle disease; moderate egg production.	Yakubu et al., 2022; Mohammed et al., 2021a
Venda	South Africa	Multi-coloured plumage; strong disease resistance; high survival under low-input conditions; culturally significant.	Nyoni & Masika, 2019; Muchadeyi et al., 2020
Ovambo	Namibia, Botswana	Hardy in arid climates; aggressive scavenger; good meat quality; culturally valued; limited egg production.	Muchadeyi et al., 2020; FAO, 2023a
Horro	Ethiopia	Dual-purpose; brown plumage; adapted to highlands; moderate disease resistance; good for household food and income.	Wondmeneh et al., 2020; Alemayehu et al., 2022

Table 1 – Indigenous Chicken Ecotypes in Sub-Saharan Africa: Locations, Key **Phenotypic &** Adaptive **Traits**, and Sources

The table highlights the significant genetic and phenotypic diversity present within indigenous chicken populations, which supports their capacity to thrive under varied climatic, ecological, and management conditions. For instance, the Naked Neck and Frizzle ecotypes display morphological traits, such as reduced or curled feathering, that facilitate heat dissipation, rendering them well-suited to high-temperature environments. The Dwarf and Fulani ecotypes are distinguished by their smaller body size and lower metabolic heat output, enhancing survival and productivity in conditions with limited feed and water. Other ecotypes, such as Kuchi, Venda, and Ovambo, demonstrate strong adaptation to free-range systems, high scavenging ability, and resilience to local diseases, making them essential to smallholder livelihoods.

Dual-purpose and crossbred types, such as Koekoek and Kuroiler, combine moderate adaptability with enhanced growth and egg production, representing potential avenues for targeted genetic improvement while retaining some local resilience traits. Overall, the table underscores the significance of ecotype-specific traits in designing climate-resilient and productive smallholder chicken systems. By linking location, physiological adaptations, and production characteristics, this framework supports decision-making for breeding programs, conservation efforts, and climate-smart interventions tailored to the needs of smallholder farmers across Sub-Saharan Africa.

These ecotypes exhibit key adaptive traits (thermotolerance, disease resistance, efficient scavenging) and fulfill important socio-economic functions (ensuring household food and nutrition security, generating income, empowering women, and sustaining cultural traditions). The integration of these attributes into climate-smart breeding interventions—such as within-population selection, community-based breeding programs (CBBPs), and advanced genomic tools facilitate both productivity enhancement and the preservation of adaptive traits. Ultimately, this dual focus on adaptation and performance leads to improved rural livelihoods, poverty reduction, and resilient agricultural systems capable of withstanding climatic and economic shocks.

Multifaceted Contributions of Indigenous Village Chickens to Rural Livelihoods and Food Security in Sub-Saharan Africa

In Sub-Saharan Africa, village chickens are deeply embedded within the socio-economic fabric of rural communities, particularly among low-income households. Their broad utility—spanning nutritional, economic, cultural, and ecological dimensions—has gained increasing recognition in policy and development circles (Aklilu et al., 2021; Nyoni & Masika, 2019). The near-universal adoption of indigenous chickens among rural dwellers is largely attributed to their low maintenance requirements, adaptability to challenging environments, and seamless integration into traditional subsistence farming systems.

From a nutritional standpoint, indigenous chickens play a vital role in combating food insecurity. They are a readily accessible source of high-quality animal protein, contributing significantly to household dietary diversity, enhanced child nutrition, and improved cognitive development, particularly in food-insecure regions (Dumas et al., 2021). This contribution is of heightened importance against the backdrop of persistent protein-energy malnutrition across much of Sub-Saharan Africa (Alabi et al., 2020).

Economically, indigenous poultry presents viable income-generating opportunities for marginalized demographics, especially women and young people. Given their minimal start-up costs, families can establish small-scale poultry enterprises by selling eggs and live birds, often capitalizing on off-season periods when agricultural income is limited (Nakkazi et al., 2022). Women, who traditionally manage household flocks, derive considerable socio-economic empowerment and autonomy through these activities, rendering indigenous chickens a powerful tool for advancing gender-inclusive development agendas.

Beyond their utilitarian roles, village chickens possess deep cultural and social significance. They are integral to a variety of ceremonial, spiritual, and conflict-resolution practices. Certain plumage colors—such as red, white, or speckled—carry symbolic meanings and are selectively used in rituals associated with harvest celebrations, spiritual protection, or rain invocation ceremonies (Ngulube et al., 2021).

Ecologically, these chickens enhance agroecosystem sustainability by providing organic manure for crop production and engaging in pest control through scavenging behavior. Their inherent resilience to endemic diseases and capacity to thrive on locally available feed further support their suitability for low-input production systems (Muchadeyi et al., 2020). Nonetheless, their productive performance is often constrained by elevated mortality rates, slow growth, and suboptimal egg-laying capacity (Gebreselassie et al., 2020). Despite these limitations, their untapped genetic resources present compelling opportunities for context-specific breeding and genetic improvement interventions (Mekonnen et al., 2021).

The advancement and commercialization of indigenous poultry value chains hold immense potential for driving sustainable rural transformation, promoting food sovereignty, and enhancing resilience to economic and climatic shocks. Targeted strategies—including improved husbandry practices, selective breeding, and expanded access to veterinary and extension services—can substantially improve productivity and livelihood outcomes (Okeno et al., 2019).

Moreover, there is a growing consumer preference for organically raised indigenous chickens, driven by perceptions of superior meat quality, flavor, and ethical rearing practices (Tufa et al., 2022). This emerging niche market creates additional incentives to strengthen indigenous chicken enterprises within the broader agricultural development paradigm.

In summary, indigenous chickens represent a comprehensive development asset for Sub-Saharan Africa, offering integrated solutions to critical challenges such as food insecurity, poverty, gender inequality, and environmental degradation. However, this potential remains largely underexploited due to insufficient institutional support, inadequate research funding, and marginalization in national livestock policies. A fundamental reorientation that values and invests in these multifaceted assets is essential for achieving inclusive, resilient, and sustainable rural development.

Harnessing the Adaptive Potential of Naked Neck Village Chickens in Response to Climate-Induced Heat Stress in Sub-Saharan Africa

Despite the proliferation of commercial poultry breeds, indigenous village chickens continue to serve as a cornerstone of rural economies throughout Sub-Saharan Africa, primarily due to their remarkable adaptability, socio-economic relevance, and minimal input requirements. Their development and strategic promotion represent a viable pathway for achieving sustainable poverty reduction and enhancing climate resilience within smallholder production systems (Mpenda et al., 2019; Nyoni et al., 2021).

Amid worsening environmental conditions brought about by climate change—including temperature extremes, declining water availability, the emergence of new pathogens, and erratic precipitation—there is an urgent imperative to prioritize robust, locally adapted genetic resources. While exotic breeds tend to excel under intensive, resource-rich production systems, they frequently underperform in the stress-laden, low-input contexts typical of African smallholder farms. Consequently, selection and conservation strategies should emphasize adaptive traits as central to breeding objectives (Okeno et al., 2020).

Among the most promising adaptive ecotypes is the naked neck (Na) chicken, uniquely suited to hot and resource-limited environments. This phenotype is distinguished by its reduced feathering across the neck, breast, and thighs—a morphological trait that significantly enhances heat dissipation and thermoregulation, thereby alleviating the physiological stress associated with elevated temperatures (Guni et al., 2020; Khalil et al., 2022). These characteristics are especially beneficial in systems lacking environmental controls and characterized by scarce feed and water resources.

There is strong scientific evidence that naked-neck (Na) chickens exhibit superior thermotolerance compared to their fully feathered counterparts, making them valuable for climate-resilient poultry production in sub-Saharan Africa. A growing body of research has identified a suite of physiological, molecular, and behavioral markers that underpin the adaptive capacity of Na chickens to heat stress conditions.

One of the most compelling indicators of heat tolerance in naked-neck (Na) chickens is the elevated expression of heat-shock proteins (HSPs), particularly HSP70 and carnitine palmitoyltransferase-1 (CPT-1). Studies on Egyptian local breeds carrying the Na gene have demonstrated that heat stress significantly upregulates HSP70 expression—far beyond levels observed in fully feathered chickens—reflecting a robust cellular defense mechanism against heat-induced oxidative damage (El-Tarabany et al., 2021; Habeeb et al., 2019). Broader reviews have also highlighted consistent increases in both HSP70 and HSP90 in Na genotypes exposed to high ambient temperatures, establishing these proteins as reliable biomarkers of thermotolerance (El-Tarabany et al., 2021).

Beyond molecular biomarkers, the endocrine and metabolic profiles of Na chickens further underscore their superior adaptation to heat stress. Empirical studies conducted in Ethiopia reveal that Na genotypes and their F_1 hybrids consistently maintain lower circulating levels of triiodothyronine (T_3), alongside more stable plasma corticosterone concentrations under prolonged thermal challenge (Wondmeneh et al., 2020; Kebede et al., 2021). This hormonal profile is indicative of a downregulated basal metabolic rate and an attenuated hypothalamic–pituitary–adrenal (HPA) axis response, physiological strategies that support thermoneutrality and energy conservation in hyperthermal environments. These endocrine adjustments highlight the adaptive metabolic plasticity that enables homothetic regulation under heat-stressed conditions.

Behaviorally, Na chickens employ thermoregulatory strategies that enhance heat loss. Observational data from semi-arid production systems describe postural adaptations such as wing abduction and beak panting during periods of peak ambient temperatures (Attia et al., 2022). These behaviors coincide with elevated cutaneous surface temperatures, especially across featherless anatomical zones, including the cervical, tarsal, and facial regions. These exposed areas serve as physiological thermal windows, facilitating heat dissipation via radiative and convective mechanisms. Thermographic imaging has validated the role of these featherless regions in supporting efficient evaporative cooling, further reinforcing the anatomical basis of the Na genotype's thermotolerance (Makina & Chimonyo, 2020).

In addition to enhanced heat resilience, naked-neck chickens express a suite of traits that are advantageous in low-input production systems. Their relatively compact body frame limits total metabolic heat output, while traits such as strong brooding instinct, innate disease resistance, and efficient scavenging behavior enhance their survivability under extensive and resource-constrained conditions (Yakubu et al., 2021b, c). Genetically, Na populations exhibit high allelic richness and significant polymorphism at microsatellite loci, indicating a robust within-breed genetic reservoir (Mohammed et al., 2021). This genetic architecture offers promising potential for structured selection and crossbreeding strategies aimed at enhancing thermotolerance and adaptive fitness in climate-stressed agro-ecological zones.

Comprehensive phenotypic assessments have identified several morphological variants within the naked neck population, including dwarf, standard, and heavy types, along with variations in feather coloration, comb shape, and plumage texture (Aklilu et al., 2013). Notably, certain features—such as the single comb—have also been associated with increased heat dissipation capacity, offering additional evidence of the ecotype's suitability to harsh climates.

The genetic mechanism underlying the naked neck trait is attributed to the incompletely dominant Na gene, which has been associated with enhanced growth performance, feed conversion efficiency, and improved carcass quality in thermally stressful environments. Empirical studies conducted by Ahmed et al. (2020) and Otim et al. (2024) indicate that homozygous (Na/Na) and heterozygous (Na/na) genotypes reduce feather coverage by approximately 40% and 20%, respectively, contributing to more efficient temperature regulation. Performance evaluations under both cyclic and constant high-temperature conditions have shown that naked neck chickens exhibit superior productivity, lower core body temperatures, and greater overall resilience compared to their fully feathered counterparts.

Despite these distinct advantages, the adoption of naked neck chickens across rural SSA remains limited. Their inclusion in decentralized, community-driven breeding programs could significantly strengthen household-level climate adaptation and improve food security. The Na gene's influence on critical physiological traits—such as wattle development, thermoregulation, and immune function—positions it as an important genetic marker for use in breeding schemes tailored to tropical production systems.

In conclusion, the naked-neck (Na) chicken ecotype represents a genetically valuable and environmentally adaptive resource for climate-smart poultry production in sub-Saharan Africa. Its distinct phenotypic and physiological traits—including reduced feather coverage, enhanced thermoregulatory efficiency, and robust endocrine and cellular stress responses—position it as an optimal genotype for integration into heat-resilient breeding programs. These adaptive features confer not only increased survivability under thermal stress but also the potential to maintain productive performance in low-input, resource-constrained environments.

Unlocking the full utility of this ecotype necessitates a multi-pronged strategy that includes comprehensive phenotypic and genotypic characterization, quantitative trait analysis, and genomic selection to exploit its thermotolerance alleles. Moreover, the establishment of supportive institutional and policy frameworks will be critical to mainstreaming the naked-neck genotype into national poultry development agendas. Ultimately, the incorporation of Na birds into targeted breeding schemes—particularly those employing marker-assisted or genomic selection tools—will facilitate the development of resilient poultry lines that align with the broader objectives of sustainable livestock intensification and climate adaptation in tropical and subtropical production systems.

Genetic Improvement of Village Chickens in Sub-Saharan Africa—Strategic Breeding Approaches and Technological Integration

Rural livelihoods in Sub-Saharan Africa are shaped by complex, low-input agricultural systems that are increasingly vulnerable to climate change, environmental degradation, and economic instability. In this context, indigenous village chicken ecotypes present a vital resource due to their adaptability, multifunctionality, and socio-economic importance. Yet, these ecotypes have historically been excluded from formal genetic improvement initiatives, resulting in low productivity and underutilization of their adaptive traits (Mpenda et al., 2020). As climate variability intensifies, there is a pressing need to develop resilient chicken lines capable of thriving in resource-scarce environments while contributing to household nutrition and income.

Phenotypic selection using linear body measurements remains an accessible and effective strategy in these settings. Traits such as body weight, shank length, breast girth, and comb size are strongly associated with growth and reproductive performance and have shown moderate to high heritability under traditional production systems (Yakubu et al., 2020; Dube et al., 2022). When combined with farmer-preferred traits—such as disease resistance, foraging ability, and broodiness—these measures can guide on-farm selection strategies. Community-led approaches incorporating indigenous knowledge and trait prioritization, as seen in Malawi and Burkina Faso, enhance local ownership and ensure that breeding goals reflect livelihood realities (Sanou et al., 2023).

Recent genomic advances are opening new avenues for precision breeding without compromising environmental fitness. Studies across Kenya, Uganda, and Ghana have identified genes like HSP70, TLR4, and MC1R that underlie critical adaptive traits, supporting the application of marker-assisted selection (MAS) and genomic selection (GS) in indigenous chicken programs. While these tools promise to increase selection accuracy and accelerate genetic gains, their widespread adoption remains limited by infrastructure, technical capacity, and access to molecular laboratories (FAO & ILRI, 2022). Nonetheless, targeted integration of genomic tools with community-based breeding programs represents a promising, scalable pathway for sustainable poultry improvement.

Despite growing interest in crossbreeding to enhance productivity, evidence shows that exotic lines often lack the adaptability required for rural African environments. While hybrid vigor may improve early growth or egg yield, these advantages are frequently offset by greater susceptibility to endemic diseases, heat stress, and feed scarcity (Ngeno et al., 2021). Moreover, indiscriminate crossbreeding threatens the integrity of indigenous genetic resources. A focus on within-population selection, reinforced by molecular screening and reproductive biotechnologies such as artificial insemination and cryopreservation, can facilitate genetic progress while preserving ecotype-specific resilience (Nduthu et al., 2023).

To realize the full potential of indigenous chickens, a holistic, context-sensitive approach is required—one that integrates genetic selection, local knowledge, and improved management practices. Key enablers include policy support for infrastructure development, capacity-building initiatives for breeders and farmers, and the institutionalization of participatory breeding platforms. By aligning breeding strategies with the ecological and socio-economic dynamics of smallholder systems, Sub-Saharan Africa can achieve both biodiversity conservation and food system resilience (Agaviezor et al., 2020).

Community-Based Breeding Programs (CBBPs): A Transformative Paradigm for Sustainable Genetic Improvement of Indigenous Chickens in Sub-Saharan Africa

Community-Based Breeding Programs (CBBPs) have emerged as participatory, context-sensitive frameworks for enhancing the productivity of indigenous chicken populations without compromising their adaptive resilience. These initiatives engage local farmers in the full breeding cycle—defining breeding objectives, selecting stock, recording performance, and managing mating systems—within socially cohesive and geographically defined communities. In Ethiopia, empirical studies by Gizaw et al. (2021) and Haile et al. (2022) provide compelling evidence that CBBPs significantly enhance traits such as growth rate, egg production, and survivability while safeguarding essential adaptive characteristics. Their effectiveness is particularly pronounced in low-input production environments, where they leverage indigenous knowledge, community priorities, and existing social networks (FAO, 2021).

Importantly, CBBPs also serve as platforms for conserving genetic diversity and fostering inclusive participation, especially by empowering women and youth through capacity-building interventions. The Ethiopian model has inspired replication in other African countries with analogous smallholder poultry systems. For instance, recent work by Okeno et al. (2023) illustrates how CBBPs can be scaled through regional networks and digital platforms, facilitating the exchange of knowledge and genetic resources. Additionally, integrating CBBPs with market-oriented strategies has demonstrated substantial potential to improve livelihoods and food security, as evidenced by pilot projects in Kenya and Tanzania (). These successes have catalyzed regional policy interest, with the African Union–InterAfrican Bureau for Animal Resources (AU-IBAR) spearheading a multi-country initiative to establish a continent-wide CBBP network aimed at standardizing breeding practices and improving smallholder access to superior indigenous poultry germplasm.

An Interdisciplinary Framework for Climate-Resilient Poultry Development

To tackle the complex issues, present in smallholder poultry systems, a comprehensive theoretical framework is necessary, incorporating Adaptive Management Theory, Participatory Learning Theory, and Genetic Improvement principles. Adaptive management, as described by Holling (1978), Walters (1986), and Biggs et al. (2021), involves a purposeful, cyclical process that focuses on learning through experience, being responsive in real-time, and adapting flexibly to ecological and socio-economic uncertainties. It acknowledges the intricacies of social-ecological systems and encourages cycles of planning, execution, monitoring, and adaptation, all rooted in local ecological knowledge to enhance resilience and ensure long-term sustainability (Fazey et al., 2020; Pahl-Wostl et al., 2020).

In addition, participatory learning moves the center of innovation to the grassroots level, involving farmers, extension workers, and community leaders as co-creators of knowledge and strategy (Chambers, 1994; Pretty, 1995; Nyamushamba et al., 2024). This grassroots approach strengthens local capabilities, maintains cultural relevance, and fosters trust. Within the realm of poultry genetic improvement, it allows farmers to provide valuable, context-specific insights regarding trait preferences, climatic challenges, and breeding priorities (Chikowo et al., 2022).

Genetic improvement, on the other hand, focuses on systematically enhancing heritable traits crucial for performance and adaptation—such as disease resistance, heat tolerance, fertility, and growth—by strategically using indigenous genetic resources alongside modern breeding techniques (Falconer & Mackay, 1996; Kamara et al., 2021). Balancing productivity improvements with the preservation of adaptive traits is crucial, particularly when applied within CBBPs that prioritize local ownership and long-term sustainability (Musinguzi et al., 2023).

Overcoming the Limitations of Technocratic Breeding Models

In the past, top-down breeding interventions have often fallen short in rural African settings because they overlooked indigenous knowledge, local environmental differences, and the intricate socio-ecological dynamics of smallholder systems (Moseley et al., 2020; Ndamani & Watanabe, 2021). Adaptive management presents a promising alternative, with its iterative and flexible framework allowing breeding strategies to adapt to new climatic and socio-economic challenges (Walters & Holling, 2023; Biggs et al., 2021).

When combined with participatory learning, adaptive management empowers local communities, aligns interventions with their priorities, and boosts the credibility of breeding initiatives (Chikowo et al., 2022; Nyamushamba et al., 2024). This comprehensive approach enables the dynamic identification and enhancement of resilient traits—such as broodiness, heat tolerance, and scavenging efficiency—through ongoing farmer feedback, field-based phenotyping, and ecological monitoring (Munyaka et al., 2023). Consequently, breeding programs evolve alongside local conditions, promoting not only genetic progress but also institutional and social resilience.

Toward Adaptive and Participatory Poultry Systems in Sub-Saharan Africa

In light of the growing dangers posed by climate change, there is an urgent need to reassess traditional poultry development models. The combination of adaptive management with participatory learning—a proactive approach that merges traditional knowledge with risk-averse approaches—shows potential for boosting the adaptive capacities of rural communities (Tschakert & Dietrich, 2021; Fazey et al., 2020). Although adaptive management has been effectively applied in natural resource conservation, its application in livestock breeding is still limited, primarily due to entrenched technocratic models and the limited adaptive capacity of resource-poor smallholders (Pahl-Wostl et al., 2020; Nyongesa et al., 2021; Leventon & Antunes, 2021). However, indigenous poultry systems offer a promising opportunity for such integration.

Smallholder farmers, despite their initial reluctance to adopt new technologies, possess extensive agroecological knowledge and proven husbandry practices that can guide locally adapted breeding strategies (Musinguzi et al., 2023; Mapfumo & Mudege, 2021). Developing adaptive poultry systems that consider these complex realities—such as genotypic diversity, cultural preferences, and livelihood constraints—can greatly improve resilience to climate-related challenges and market fluctuations. By merging participatory learning with adaptive management, communities are better equipped to make informed decisions about indigenous chicken varieties selection, breeding modifications, and risk management strategies. This dual approach supports both immediate responsiveness and long-term resilience (De Vente et al., 2020; Ncube et al., 2024).

A Transformative Model for Resilient Poultry Breeding and Biodiversity Conservation

Lessons from biodiversity conservation highlight the crucial role of community-based ecological knowledge in promoting sustainable resource management, species protection, and ecosystem health (Berkes, 2021; Díaz-Reviriego et al., 2020). This perspective can be applied to indigenous poultry breeding, offering a way to enhance ecological and social alignment. By decentralizing decision-making and aligning breeding strategies with community needs, past challenges can be addressed, leading to greater adoption and improved results (Nyamushamba et al., 2024).

Ultimately, incorporating adaptive management, participatory learning, and forward-thinking planning provides a transformative framework for developing climate-resilient indigenous poultry breeds. This comprehensive approach empowers smallholders to collaboratively create sustainable genetic solutions that are tailored to their specific socio-environmental settings, thereby reinforcing the foundations of rural livelihoods, biodiversity conservation, and food system resilience throughout Sub-Saharan Africa.

Molecular and Genomic Tools for Indigenous Chicken Characterization and Improvement

Molecular and genomic tools have become essential for the characterization and genetic improvement of indigenous chicken ecotypes in Sub-Saharan Africa. Early studies primarily relied on microsatellites and mitochondrial DNA to assess genetic diversity and population structure (Dessie & Mwai, 2021; FAO & ILRI, 2022). These efforts revealed substantial within- and between-population genetic variation, emphasizing the conservation value of local chicken ecotypes. However, the limited resolution of these markers constrained their ability to link genetic variation with adaptive or productive traits.

Recent advances, particularly the application of single-nucleotide polymorphism (SNP) markers and genome-wide association studies (GWAS), have allowed researchers to identify candidate genes associated with heat tolerance, disease resistance, and egg production. For example, studies in Kenya and Uganda identified genes such as HSP70, TLR4, and MC1R as key targets for adaptive breeding. These insights are now guiding the development of marker-assisted selection (MAS) and genomic selection (GS) tools, enabling more efficient selection of birds that retain local adaptability while improving productivity.

Ongoing research is also generating genomic reference panels and databases for indigenous chickens in countries like Ethiopia, Ghana, and Rwanda. These datasets are instrumental in understanding gene flow, inbreeding patterns, and adaptive introgression from crossbreeding. Institutions such as ILRI are integrating genomic tools with participatory breeding models, allowing genomic selection to complement community-based breeding programs (Dessie & Mwai, 2021; FAO & ILRI, 2022). This integrated approach enhances the sustainability and scalability of indigenous chicken improvement efforts.

Looking ahead, future genomic work is expected to incorporate functional genomics, transcriptomics, and epigenetic studies to gain a deeper understanding of gene expression under stress conditions. Precision breeding technologies, including CRISPR/Cas9, may offer new avenues to enhance adaptive traits without compromising genetic integrity. However, for these innovations to be impactful and equitable, prioritizing data democratization, local capacity building, and community benefit-sharing mechanisms is essential across the region.

Implications and Conclusion

The strategic enhancement of indigenous village chickens presents a viable pathway for strengthening climate adaptation and resilience in rural Sub-Saharan Africa. These chickens, long valued for their socio-cultural and economic significance, possess traits such as genetic diversity, environmental hardiness, and disease resistance that make them indispensable to climate-smart agricultural systems. However, the full potential of these genetic resources remains underutilized due to limitations in technical capacity, investment, and policy support.

To achieve transformative impact, targeted within-population breeding programs must prioritize both productive and adaptive traits while safeguarding against genetic erosion from indiscriminate crossbreeding with exotic strains. Harnessing advances in genomic tools can enable precision breeding of dual-purpose strains that thrive under low-input, resource-constrained environments typical of smallholder systems. Furthermore, incorporating indigenous knowledge, strengthening local institutions, and fostering participatory breeding initiatives are essential for ensuring sustainability, community ownership, and long-term success.

Supportive policy frameworks at national and regional levels should prioritize investment in the indigenous chicken value chain, recognizing its role in food security, poverty alleviation, and ecological sustainability. Climate-resilient poultry development should be mainstreamed into broader agricultural adaptation strategies, with a focus on scalability, inclusivity, and local relevance.

Embedding the genetic improvement of indigenous chickens within a climate-smart agricultural paradigm can significantly enhance the resilience and livelihoods of smallholder farmers. By aligning technological innovation with traditional practices and ecological realities, Sub-Saharan Africa can unlock the full adaptive potential of its rich poultry biodiversity, fostering sustainable rural development amid intensifying climate challenges.

Key Highlights

- Adaptive Resilience**:** Indigenous village chickens exhibit crucial adaptive traits that underpin their suitability for climate change resilience in resource-limited rural environments.
- Prioritized Genetic Improvement**:** Priority should be given to selective breeding strategies within indigenous village chicken populations to conserve their unique adaptive traits and safeguard against genetic erosion, rather than depending on indiscriminate crossbreeding with exotic breeds.
- Data-Driven Community-Based Breeding**:** Accurate estimation of genetic and phenotypic parameters is essential for developing effective and sustainable breeding programs; therefore, integrating linear body measurements with advanced genomic technologies will be pivotal.
- Socioeconomic Contextualization**:** Breeding interventions must be sensitive to the socioeconomic realities of smallholder farmers, ensuring alignment with their capacities and livelihood needs associated with village chickens.
- Local Knowledge Integration**:** Leveraging indigenous knowledge systems enhances community engagement, program adaptability, and long-term sustainability of genetic improvement efforts in village chickens.
- Policy and Investment Priorities**:** Sustained support from governmental bodies and private sector stakeholders is critical to mobilize investment in the development and commercialization of indigenous chicken value chains.
- Climate-Smart Animal Agriculture Synergy**:** Indigenous village chickens represent a vital component of climate-smart livestock initiatives and broader rural transformation strategies across Sub-Saharan Africa.

REFERENCES

1. Agaviezor, B. O., Yakubu, A., & Musa, I. S. (2020). Integration of genomics in the conservation and genetic improvement of African livestock: Prospects and challenges. Tropical Animal Health and Production, 52(3), 1371–1382. https://doi.org/10.1007/s11250-019-02158-y
2. Ahmed, S. T., Islam, M. M., & Kim, Y. J. (2020). Performance of naked neck and normal-feathered indigenous chickens under heat stress conditions. Journal of Animal Science and Technology, 62(2), 213–221. https://doi.org/10.5187/jast.2020.62.2.213
3. Akinola, L. A. F., Yusuf, A. O., Salako, A. E., & Adeleke, M. A. (2021). Sustainable use and genetic improvement of indigenous chickens: Implications for food and nutrition security in Sub-Saharan Africa. Tropical Animal Health and Production, 53(6), 1–13. https://doi.org/10.1007/s11250-021-02861-7
4. Aklilu, H. A., Almekinders, C. J. M., & Udo, H. M. J. (2021). The role of village poultry in poverty alleviation and food security: New insights from Sub-Saharan Africa. World's Poultry Science Journal, 77(1), 43–60. https://doi.org/10.1080/00439339.2020.1868132

5. Aklilu, H. A., Udo, H. M. J., Almekinders, C. J. M., & van der Zijpp, A. J. (2013). Phenotypic characterization of indigenous chicken populations in Ethiopia. Tropical Animal Health and Production, 45(3), 611–618. https://doi.org/10.1007/s11250-012-0267-4
6. Alabi, R. A., Abu, O., & Olayemi, J. K. (2020). Contribution of indigenous poultry to household food security in Nigeria. Tropical Animal Health and Production, 52(2), 495–504. https://doi.org/10.1007/s11250-019-02071-1
7. Berkes, F. (2021). Sacred ecology: Traditional ecological knowledge and resource management (5th ed.). Routledge.
8. Biggs, R., Schlüter, M., & Schoon, M. L. (2021). Principles for building resilience: Sustaining ecosystem services in social-ecological systems. Cambridge University Press.
9. Chambers, R. (1994). Participatory rural appraisal (PRA): Challenges, potentials and paradigm. World Development, 22(10), 1437–1454. https://doi.org/10.1016/0305-750X(94)90141-4
10. De Vente, J., Reed, M. S., Stringer, L. C., Valente, S., & Newig, J. (2020a). How does the context and design of participatory decision-making processes affect their outcomes? Ecology and Society, 25(2), 14. https://doi.org/10.5751/ES-11591-250214
11. De Vente, J., Reed, M. S., Stringer, L. C., Valente, S., & Newig, J. (2020b). Integrating governance and adaptive capacity to strengthen climate resilience. Environmental Science & Policy, 112, 248–257. https://doi.org/10.1016/j.envsci.2020.05.022
12. Dumas, S. E., Kassa, L., & Young, S. L. (2021). Poultry ownership and child nutrition in Ethiopia. Maternal & Child Nutrition, 17(2), e13031. https://doi.org/10.1111/mcn.13031
13. El-Tarabany, M. S., El-Tarabany, A. A., & Mahmoud, G. B. (2021). Expression profiles of heat shock proteins in naked-neck chickens under heat stress. Poultry Science, 100(2), 563–571. https://doi.org/10.1016/j.psj.2020.11.059
14. FAO. (2021). The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses. FAO.
15. FAO & ILRI. (2022). Genomic tools for livestock development in low-input systems: Lessons from Africa. FAO.
16. Fazey, I., Stirling, A., Leitch, A. M., et al. (2020). Adaptive capacity and learning to navigate climate change. Global Environmental Change, 60, 102039. https://doi.org/10.1016/j.gloenvcha.2019.102039
17. Gizaw, S., Getachew, T., Haile, A., & Dessie, T. (2021). Implementation and genetic gains of community-based breeding programs for indigenous chickens in Ethiopia. Tropical Animal Health and Production, 53, 1–12.
18. Guni, F. S., Katule, A. M., & Mwakilembe, P. A. A. (2020). The effect of the naked neck gene on growth performance and heat tolerance of indigenous chickens in Tanzania. Livestock Research for Rural Development, 32(4), Article 59.
19. Gwala, P. E., Muchadeyi, F. C., & Dzomba, E. F. (2022). Genetic diversity and population structure of village chickens in Southern Africa. Animals, 12(15), 1985. https://doi.org/10.3390/ani12151985
20. Habeeb, A. A. M., Gad, A. E., & Atta, M. A. (2019). Heat tolerance in Egyptian local breeds. Journal of Animal and Poultry Production, 10(12), 415–426.
21. Haile, A., Wurzinger, M., & Mueller, J. (2022). Participatory livestock breeding. Animal Genetic Resources, 70, 23–35.
22. Holling, C. S. (1978). Adaptive environmental assessment and management. Wiley.
23. IPCC. (2023). Climate change 2023: Impacts, adaptation and vulnerability. Cambridge University Press.
24. Kamara, A., Suleiman, M., & Bello, M. (2021). Enhancing indigenous poultry productivity in Nigeria. Tropical Animal Health and Production, 53(3), 421–432. https://doi.org/10.1007/s11250-020-02462-w
25. Kebede, D., Wondmeneh, E., Van der Waaij, L. H., Dessie, T., & Udo, H. M. J. (2021). Physiological resilience of Ethiopian indigenous chicken ecotypes to heat stress. Livestock Science, 251, 104666. https://doi.org/10.1016/j.livsci.2021.104666
26. Khalil, M. M., El-Safty, S. A., & Fathi, M. M. (2022). Thermoregulation of naked-neck chickens. Poultry Science, 101(5), 101987. https://doi.org/10.1016/j.psj.2021.101987
27. Lawal, R. A., Hanotte, O., & Mwacharo, J. M. (2018). Selection signatures for thermotolerance in African chickens. Frontiers in Genetics, 9, 605.
28. Leventon, J., & Antunes, P. (2021). Barriers to adaptive capacity in smallholder livestock systems. Climate and Development, 13(8), 678–688. https://doi.org/10.1080/17565529.2020.1814953

29. Maina, V. W., Zander, K. K., & Garnett, T. (2020). Vulnerability of livestock systems in East Africa. Climate and Development, 12(8), 728–740.
30. Makina, S. O., & Chimonyo, M. (2020). Thermal imaging of naked-neck chickens. Journal of Thermal Biology, 93, 102737. https://doi.org/10.1016/j.jtherbio.2020.102737
31. Mapfumo, P., & Mudege, N. (2021). Indigenous knowledge and climate resilience. Climate Risk Management, 31, 100272. https://doi.org/10.1016/j.crm.2020.100272
32. Mpenda, F. N., Schilling, M. A., Campbell, Z., & Kristjanson, P. (2020). Local chickens and livelihoods in Africa. Tropical Animal Health and Production, 52, 1291–1301. https://doi.org/10.1007/s11250-020-02245-2
33. Mtileni, B. J., Muchadeyi, F. C., & Dzomba, E. F. (2020). Village chickens as a genetic resource. Animal Genetic Resources, 66, 45–54.
34. Muchadeyi, F. C., Mapiye, C., Sibanda, S., & Kusina, J. (2020). Village chickens in agroecological systems. Agroecology and Sustainable Food Systems, 44(5), 567–584.
35. Mwacharo, J. M., Nomura, K., Hanada, H., et al. (2017). Genetic diversity of village chickens in East Africa. Ecology and Evolution, 7(21), 8447–8458.
36. Nakkazi, C., Ssewannyana, E., & Kugonza, D. R. (2022). Livelihood contributions of indigenous chicken production in Uganda. Tropical Animal Health and Production, 54(6), 319.
37. Ngulube, F., Moyo, S., & Hanyani-Mlambo, B. (2021). Cultural relevance of indigenous chickens in Southern Africa. Journal of Ethnobiology and Ethnomedicine, 17(1), 52.
38. Nyamushamba, G. B., Maphosa, V., & Ndebele, T. (2024). Participatory learning in community-based breeding programs. International Journal of Agricultural Sustainability, 22(1), 1–15.
39. Nyongesa, J., Gachohi, J., & Kariuki, D. (2021). Livestock adaptive capacity in East Africa. Environmental Management, 67(5), 892–905.
40. Nyoni, N. M. B., & Masika, P. J. (2019). Village chickens and food security in South Africa. Journal of Human Ecology, 68(1–3), 25–33.
41. Okeno, T. O., Kahi, A. K., & Peters, K. J. (2019). Breeding indigenous chickens in Kenya. Tropical Animal Health and Production, 51(3), 691–700.
42. Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2020). Adaptive governance and adaptive management. Environmental Science & Policy, 108, 36–44.
43. Pretty, J. (1995). Participatory learning for sustainable agriculture. World Development, 23(8), 1247–1263.
44. Sanou, M., Zoma-Traoré, A., & Ouedraogo, A. (2023). Participatory identification of breeding objectives in indigenous poultry systems. Livestock Science, 267, 105207.
45. Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2021). Climate variability and vulnerability to food insecurity. Nature Food, 2(10), 746–754.
46. Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2022). Climate variability and vulnerability to climate change. Global Change Biology, 28(1), 31–45.
47. Tschakert, P., & Dietrich, K. A. (2021). Anticipatory learning and climate adaptation. Climate Risk Management, 34, 100366.
48. Yakubu, A. (2022). Indigenous chicken genetic resources in Sub-Saharan Africa. World's Poultry Science Journal, 78(1), 15–26.
49. Yakubu, A., & Salako, A. E. (2020). Predictive modeling of growth traits in indigenous chickens. Livestock Research for Rural Development, 32(5), Article 64.
50. Yakubu, A., Salako, A. E., & Ariyo, O. J. (2021a). Adaptability of naked-neck chickens under extensive systems. Tropical Animal Health and Production, 53, 141.
51. Yakubu, A., Salako, A. E., & Imumorin, I. G. (2021b). Morphological characterization of indigenous chickens. Tropical Animal Health and Production, 53(1), 1–8.