

A Review on Genetic Improvement of Indigenous Goats in Kenya's Arid and Semi-Arid Lands: Harnessing Community-Based Breeding Programs and Genomic Approaches

¹Kipkorir, Koech Vincent

¹Department of Animal Sciences, Chuka

ARTICLE INFORMATION	ABSTRACT
Article history: Published: October 2026 Keywords: Indigenous Goats Genetic Improvement Community-Based Breeding ASALs Genomic Selection	Indigenous goats play a vital role in sustaining livelihoods in Kenya's arid and semi-arid lands (ASALs) due to their resilience in harsh environmental conditions. Despite their adaptability, productivity remains low due to poor breeding practices, limited data systems and minimal access to improved genetics. This review examines how different livestock production systems influence breeding outcomes and evaluates both conventional and genomic breeding approaches to livestock genetic improvement. Extensive pastoralism, transhumance, agro-pastoralism, semi-intensive and intensive systems are analyzed in relation to their conduciveness to genetic improvement. The review finds that community-based breeding programs (CBBPs) particularly when integrated with genomic selection represent the most practical strategy for improving productivity in low-input systems. Evidence from Ethiopia, Kenya and other African countries demonstrates that CBBPs have achieved substantial genetic gains in body weight, kidding rate and farmer income. Genomic selection offers opportunities to accelerate genetic gain especially for traits that are difficult to measure such as disease resistance, heat tolerance and feed efficiency. However, challenges including low effective population sizes ($N_e = 4.77-5.19$), limited phenotyping infrastructure and weak national breeding policies must be addressed. Achieving long-term success will depend on investments in farmer training, infrastructure, data recording and supportive national breeding policies.

1. Introduction

Indigenous goats play an indispensable role in sustaining rural livelihoods in Kenya's arid and semi-arid lands (ASALs) where climatic variability, recurrent droughts and limited pasture resources challenge the survival of most livestock species. According to the Kenya National Bureau of Statistics (2019), goats constitute one of the largest livestock populations in ASAL counties accounting for over 30 million animals nationally. They serve as a major source of meat, milk, skin, manure and income while also fulfilling important cultural, social and ceremonial roles. Their ability to utilize shrubs, browse hardy vegetation and maintain productivity during prolonged feed scarcity makes them uniquely suited to the ASAL environment (Peacock, 2005; Devendra, 2010). Despite their ecological fitness, indigenous goats exhibit relatively low productivity compared to improved or exotic breeds. Studies by Kosgey et al. (2006) and Bett et al. (2009) report deficiencies in growth rate, carcass quality, reproductive efficiency and milk output among indigenous goat populations. For instance, average birth weights in indigenous goats range from 2.0-2.5 kg with weaning weights of 5-8 kg, significantly lower than improved or exotic crosses. These challenges stem largely from the absence of structured breeding programs, uncontrolled mating, minimal recordkeeping and limited dissemination of improved germplasm (Ojango et al., 2011). Additionally, ASAL communities face infrastructural constraints, poor extension support and low access to breeding technologies such as artificial insemination (Kahi et al., 2006).

Genetic studies indicate a very low effective population size (N_e) for indigenous goats estimated at 5.19 for Galla and 4.77 for Small East African (SEA) goats with inbreeding rates increasing by 0.04-0.05 per generation (Ng'ang'ombe et al., 2019; Kichamu et al., 2024). Such low N_e values highlight the risk of genetic erosion and underscore the urgency of structured genetic improvement. The majority of Kenyan indigenous goats are not distinct and their genetic structure is very diverse with distinct haplogroups present (Githui et al., 2016). Genetic diversity showed weak positive Tajima D values for Kenyan indigenous goats, indicating they are under different selection pressure compared to other global populations (Githui et al., 2016). Improving indigenous goat productivity through genetic enhancement is therefore a central strategy for strengthening food security and livelihood resilience in ASAL regions (Mueller et al., 2015). This review, therefore, integrates evidence from global and regional studies to examine production systems, breeding objectives, genetic evaluation tools and modern selection strategies. It emphasizes the relevance of community-based breeding programs (CBBPs) and the transformative potential of genomic selection as sustainable pathways for improving indigenous goat genetic resources. The purpose of this review is to analyze current genetic improvement strategies for indigenous goats in Kenya's arid and semi-arid lands and to identify context-appropriate, sustainable breeding approaches that integrate both traditional and genomic tools. This review contributes to livestock development discourse by bridging scientific innovation with grassroots breeding practices offering sustainable pathways for improving productivity and preserving genetic diversity in climate-vulnerable regions.

2. Livestock Production Systems in ASALs

2.1 Extensive Production Systems

Extensive pastoralism is the dominant livestock production system in Kenya's ASALs accounting for up to 70% of the national goat population (Escareño et al., 2012). In this system, goats graze freely across vast communal lands relying exclusively on natural vegetation. Herd mobility is central to pastoral adaptation allowing households to track seasonal forage availability across landscapes (Schoof & Luick, 2018). Although extensive systems minimize feed and labor costs, their unregulated mating practices hinder systematic selection for superior genetics. Performance recording is nearly impossible due to mobility and herd mixing while exposure to predators, diseases and nutritional stress leads to high kid mortality (Ademosun, 2003; Ojango et al., 2023). Changing climatic conditions have resulted in increased frequency and severity of droughts in ASALs with 2.6 million animals dying in Kenya due to drought between 2020 and 2023 (Ojango et al., 2024). These constraints limit genetic gain despite the system's resilience advantages.

2.1.1 Transhumance and Agro-Pastoralism

Transhumance involves seasonal herd movement in search of forage and water, typically between dry-season grazing reserves and wet-season pastures. While transhumance enhances resilience during prolonged droughts, it complicates genetic improvement due to difficulties in keeping pedigree records, identifying sires and ensuring controlled mating (Ng'ang'ombe et al., 2011). Agro-pastoralism which integrates livestock and crop production enhances sustainability by recycling nutrients and providing crop residues as feed (Amankwah et al., 2012). Livestock in agro-pastoral systems contribute manure for soil fertility and serve as insurance against crop failure. These systems are more conducive to genetic improvement than transhumance, however, they require breeding programs tailored to mixed-farming constraints.

2.2 Semi-Intensive Systems

Semi-intensive systems are common in agro-pastoral zones where households have access to fenced grazing plots and provide supplementary feeding particularly during dry periods. Goats are grazed during the day but housed at night to minimize predation and enhance disease control (Getahun et al., 2005). This system improves reproductive management by enabling controlled mating, systematic buck rotation and monitoring of pregnancy outcomes. Semi-intensive systems offer an ideal environment for implementing performance recording, pedigree tracking and early weaning strategies. Studies in Ethiopia (Haile et al., 2011) show that semi-intensive systems significantly increase kid survival, average daily gain and reproductive efficiency.

2.3 Intensive Systems

Intensive systems involve full-time confinement of goats, provision of formulated rations, and regular veterinary supervision. Although resource-intensive, intensive systems allow precise control of mating, nutrition and health enabling reliable recording of growth, milk yield, feed conversion efficiency and reproductive traits (Escareño et al., 2012). Dairy goat projects in Kenya demonstrate that intensive systems can increase milk yield up to 3-4 times that of indigenous goats (Chenyambuga et al., 2012). However, adoption remains limited in ASALs due to high feed costs, limited water supply and labor demands.

3. Genetic Improvement of Indigenous Goats

3.1 Defining Breeding Objectives

Breeding objectives outline the traits prioritized for improvement, based on farmer needs, market preferences and environmental constraints. For indigenous goats in ASALs, production traits such as growth rate, carcass weight, milk yield and reproductive efficiency are important but functional traits like survivability, mothering ability, heat tolerance, disease resistance and drought resilience are vital for maintaining herd productivity under extreme conditions (Kosgey, 2004; Baker & Rege, 1994). Traditional economic models using profit functions and bio-economic simulations (Bekman & van Arendonk, 1993) emphasize market-driven traits but neglect survival traits which are central to ASAL systems. Recent studies advocate participatory approaches that incorporate farmer preferences into breeding objectives. Kariuki et al. (2017) demonstrated that choice experiments and non-market valuation techniques provide more realistic assessments of trait importance in marginal environments. In Ethiopia, Haile et al. (2019) found that breeding objectives defined through farmer participation led to stronger adoption and sustainability of community breeding programs. Similarly, Wurzinger et al. (2011) emphasized that participatory approaches ensure breeding goals align with local production systems and market demands. The integration of indigenous knowledge with farmers' preferred phenotypes and breeding practices is essential for designing effective breeding programs (Ojango et al., 2023).

3.2 Genetic Evaluation and Selection Strategies

3.2.1 Phenotypic Selection

Conventional genetic evaluation uses pedigree and performance data to estimate breeding values. The Best Linear Unbiased Prediction (BLUP) method, widely adopted in livestock breeding adjusts for environmental differences and improves accuracy of selection (Mrode, 2014). BLUP requires structured recording systems that capture birth weights, growth performance, reproductive traits and pedigree information. Studies in Kenya (Ojango et al., 2004) and Tanzania (Chenyambuga et al., 2012) demonstrate that BLUP evaluations significantly enhance selection accuracy in small ruminants. However, most ASAL communities lack the infrastructure and capacity for routine data collection. This presents a major limitation for applying BLUP-based selection in indigenous goat populations. The basic building blocks of conventional breeding programs for small ruminants in most developing countries are lacking and genomic information can help overcome some limitations through parent verification using genomic matrices to estimate breeding values (Mrode et al., 2018).

3.2.2 Marker-Assisted Selection (MAS)

Marker-assisted selection uses DNA markers associated with major genes governing specific traits. While MAS has proven effective for traits like disease resistance, it is less useful for complex traits controlled by many genes (Heidaritabar, 2016; Dekkers, 2004). Due to the polygenic nature of most economically important traits in goats, MAS plays a limited role in indigenous goat

improvement. However, MAS can complement conventional selection for specific traits with known major genes, such as the polled gene or disease resistance loci. Recent genomic advancements have identified key genes such as MSTN, IGF1 and CAST that influence muscle growth, fat deposition and meat tenderness which are critical for improving growth performance and carcass characteristics in goats (Ncube et al., 2025).

3.2.3 Genomic Selection

Genomic selection overcomes the limitations of phenotypic selection and MAS by using thousands of SNP markers across the genome to estimate breeding values. Meuwissen, Hayes, and Goddard (2001) demonstrated that GS can predict genetic merit more accurately than pedigree-based tools especially for traits influenced by many genes. GS identifies superior animals early, reduces generation interval and accelerates genetic gain (Goddard & Hayes, 2007). Hayes et al. (2009) found that GS increases accuracy by up to 50% and reduces generation intervals by more than half in dairy cattle. Similar gains are achievable in goats when coupled with proper training populations and genotyping infrastructure. In small ruminants, genomic tools are gaining momentum. Biscarini et al. (2015) report successful implementation of GS in local sheep and goat breeds emphasizing its potential for conserving genetic diversity while improving performance. GS is particularly valuable in ASAL systems because it enables accurate selection even when pedigree records are poorly maintained. The primary challenge remains the need for sufficiently large training populations which can be addressed through regional collaboration and shared reference populations (Haile et al., 2020a). Genomic selection has been demonstrated to increase the rate of genetic gain and reduce inbreeding in different livestock species (de Roos et al., 2011). Recent advances in low-density SNP panels and imputation strategies have reduced genotyping costs, making GS more accessible for developing countries (Wiggans et al., 2017; Meuwissen et al., 2016).

3.3 Integration of Genomic Tools into Breeding Programs

The integration of genomic tools into existing breeding programs requires careful consideration of infrastructure, cost and capacity. Carillier-Jacquin et al. (2016) demonstrated that genomic selection can be implemented in small populations using combined reference populations. For indigenous goats in ASALs, a stepwise approach is recommended which include; (i) establishing phenotyping and recording systems, (ii) building reference populations through regional collaboration, (iii) implementing low-density SNP panels and (iv) gradually transitioning to full genomic selection. This approach allows for capacity building while generating immediate benefits from improved selection accuracy (Mrode et al., 2018).

The potential for genomic selection in developing countries is substantial. Phenotypic and pedigree information remains problematic to collect, cohorts of contemporaries are often of inadequate size, breeding infrastructures are non-existent and advanced reproductive technologies are difficult to apply (Mrode et al., 2018). These drawbacks can be circumvented through CBBPs which can provide a framework to implement basic recording and design mating schemes. CBBP together with case-control protocols for use in genome-wide association analyses offer great opportunity for identifying genomic regions with major gene effects that could be used for genomic selection or introgression (Mrode et al., 2018).

4. Breeding Programs

4.1 Nucleus Breeding Programs

Nucleus breeding programs consist of elite herds where superior animals are intensively selected and their genetics disseminated to the wider population. Closed nucleus schemes generate genetic improvement solely within the nucleus optimizing selection intensity but increasing inbreeding risk (Rewe et al., 2004). Open nucleus systems mitigate this by allowing genetically superior animals from the base population to join the nucleus enhancing genetic diversity and reducing inbreeding (Rege et al., 2001). However, both systems require structured recordkeeping, advanced infrastructure and significant financial investment. In ASAL contexts, nucleus programs are often impractical due to these requirements. The Kenya Dual Purpose Goat (KDPG) breeding program started in 1980 was a notable attempt to develop a synthetic goat breed combining environmental adaptability of indigenous breeds with improved productivity (Kahi et al., 2006).

4.2 Community-Based Breeding Programs (CBBPs)

CBBPs have gained recognition as the most practical approach for genetic improvement in smallholder and pastoral systems. In Ethiopia, the implementation of CBBPs led to significant increases in body weight, kidding rate and farmer income across multiple sheep and goat communities (Haile et al., 2011; Mueller et al., 2006). CBBPs emphasize farmer participation in defining breeding objectives, selecting breeding bucks and managing communal breeding schemes. They incorporate low-cost strategies such as buck rotation, communal grazing and simple performance recording. CBBPs are highly suited to ASAL regions due to their reliance on local knowledge, their adaptability to low-input systems and their capacity to preserve adaptive traits. Integrating genomic tools into CBBPs as proposed by Wurzinger et al. (2011) would significantly improve selection accuracy without imposing unrealistic data recording demands on farmers. Haile et al. (2020a) demonstrated that CBBPs generated substantial genetic gains and socioeconomic benefits with genetic trends for body weight increasing by 0.5-1.0 kg per year in some communities. The success of CBBPs depends on strong farmer organizations, continuous technical support and linkage to markets (Gizaw et al., 2013).

Evidence from CBBPs in Malawi and Uganda targeting indigenous village goats has shown reported improvements in kid survival and growth with emerging price premiums for improved stock (Kaumbata et al., 2021). In Uganda, CBBPs organized via producer groups with communal selection and controlled mating with selected bucks have shown positive economic returns (Lwiza et al., 2024). In Ethiopia, CBBPs for Abergelle goats documented higher birth weights for progeny of selected bucks and measurable milk yields under village conditions (Birhanie et al., 2018). Modeling for pastoral Borana goats showed feasible genetic gains and cost-effective designs for pastoral goat CBBPs (Getachew et al., 2022). The FARM-Africa Goat Improvement Programme implemented a community-based goat improvement project in five countries through FARM Africa such as Ethiopia, Tanzania, Kenya, Uganda and South Africa (Peacock et al., 2011). The breeding strategy involved cross-breeding local goats with Toggenburg bucks in

community-managed buck stations. All key inputs were in the hands of farmers supported by private animal healthcare providers who formed a breeders' association to manage the breeding of improved goat genotypes (Ojango et al., 2010). A high demand for breeding stock led to high off-take rates through sale of young goats at high prices though this sometimes hindered continued genetic improvement as animals were sold and performance records were lost (Peacock et al., 2011).

The ILRI-Ministry of Agriculture collaboration in Kenya established Core Innovation Groups (CIGs) comprising 30 pastoral households in Isiolo, Marsabit, and Turkana Counties to model new practices for wider adoption (Ojango et al., 2023). The study showed that pastoral communities are open to technological interventions for animal productivity with adoption enhanced by experiential capacity development activities adapted to the education level of different communities. Prevention of diseases was the most readily adopted followed by crossbreeding using indigenous breeds of sheep and goats from other arid areas of Kenya (Ojango et al., 2023). In Turkana County, a one-year EU-funded Community-Based Breeding Program targeting 155 households and more than 4,650 indigenous goats was launched in 2026 (Turkana County Government, 2026). The program applies a community-driven breeding approach aimed at improving animal performance while safeguarding locally adapted breeds. The initiative is being implemented by Welthungerhilfe in partnership with FAO and the Turkana County Department of Livestock Development. The program adopts a participatory breeding model that places communities at the center of decision-making, working alongside livestock experts to identify, select and manage superior breeding animals based on traits valued by pastoralists (Turkana County Government, 2026).

4.3 National Breeding Programs and Policy Frameworks

National breeding programs provide the institutional framework for genetic improvement. In Kenya, the Kenya Animal Genetic Resources Centre (KAGRC) and the Kenya Agricultural and Livestock Research Organization (KALRO) are mandated to conserve and improve indigenous livestock genetic resources. The Kenya National Livestock Policy (2008) was formulated with an aim of addressing challenges facing the livestock subsector in the fields of breeding, nutrition and feeding, disease control, value addition and marketing, and research and extension (FAO, 2010). Specific objectives include establishing appropriate management systems for the sustainable development of the livestock industry, effectively improving and conserving available animal genetic resources and achieving effective control of animal diseases and pests (FAO, 2010). Specific achievements attributable to the National Livestock Policy include the establishment of the Kenya Animal Genetic Resources Centre through a legal notice, tasked with establishing a gene bank that will take custody of tissues, DNA, semen and embryos from all important livestock species in Kenya (FAO, 2010). The policy also led to the conversion of livestock farms and sheep and goat stations into conservation farms for breeds that are considered vulnerable especially those threatened by cross-breeding and natural disasters (FAO, 2010). Regulation of all breeding-service providers and the establishment of farmer groups, cooperatives and other community-based structures to provide artificial insemination services were also achieved (FAO, 2010). However, weak coordination between research institutions, extension services and farmer organizations limits the impact of these programs (Kahi et al., 2006). The National Livestock Policy (2008) and the Kenya Vision 2030 recognize the importance of indigenous livestock but lack specific implementation strategies for ASAL regions. The policy is intended to contribute to the development of breeding programs for indigenous AnGR, but provisions related to AnGR management need to be elaborated in more detail (FAO, 2010). Strengthening national breeding policies, investing in infrastructure and building human capacity are essential for sustainable genetic improvement (FAO, 2015).

5. Population Statistics of Kenyan Indigenous Goats

The heritability estimates for growth traits in Kenyan indigenous goats range from 0.25 to 0.40 indicating moderate genetic control. This suggests that genetic improvement through selection is feasible but will require sustained efforts over multiple generations. The low effective population sizes ($N_e = 4.77$ -5.19) are a major concern as they indicate high risk of inbreeding depression and loss of genetic diversity. The maximum generation traced for Galla and SEA populations was 14.6 and 14.5, respectively with average generation intervals of 3.84 and 4.4 years (Kichamu et al., 2024). The average increase in the rate of inbreeding per generation for Galla and SEA was 0.04 and 0.05 with the effective ancestors and founders ratio being the same (1.00) for both breeds (Kichamu et al., 2024). Fifty percent of the genetic variability in the populations was contributed by 3 and 1 ancestor for Galla and SEA, respectively (Kichamu et al., 2024). Strategies to increase N_e include promoting gene flow between populations, avoiding mating of close relatives and establishing open nucleus breeding schemes (Ng'ang'ombe et al., 2019; FAO, 2015). The current breeding programs should be changed to avoid future genetic bottlenecks in these populations (Kichamu et al., 2024). Results were as shown in Table 1.

Table 1: Population statistics and genetic parameters of Kenyan indigenous goats

Breed/Population	Approx. Population Size (Kenya)	Heritability (h^2) for Growth Traits	Average Growth/Production Traits	Effective Population Size (N_e)	Reference
Galla	1.5 million	0.25–0.35	Birth weight: 2.2–2.5 kg; Weaning weight: 6–8 kg	5.19	Ng'ang'ombe et al. (2019); Kichamu et al. (2024)
Small East African (SEA)	5.0 million	0.25–0.40	Birth weight: 2.0–2.4 kg; Weaning weight: 5–7 kg	4.77	Ng'ang'ombe et al. (2019); Kichamu et al. (2024)
East African Boran × Local cross	—	0.28–0.38	Birth weight: 2.5–2.8 kg; Yearling weight: 18–22 kg	—	Mugambi (2006)
Indigenous Mixed ASAL breeds	30 million	0.25–0.40	Kid survival rate: 60–70%; Milk yield: 0.5–1 L/day	5–6	Haile et al. (2011); Bett et al. (2009)

6. Challenges and Opportunities

6.1 Challenges

Several challenges constrain genetic improvement of indigenous goats in Kenya's ASALs. First, weak data recording systems make it difficult to estimate breeding values accurately. Second, low effective population sizes increase the risk of inbreeding depression and genetic drift. Third, limited access to genotyping technologies and high costs constrain the implementation of genomic selection. Fourth, weak extension services and limited farmer training reduce the adoption of improved breeding practices (Kahi et al., 2006; Kosgey et al., 2006). Additionally, only a few African countries have functional research laboratories or centers capable of completing genomics analyses to improve livestock (Mrode et al., 2018). The lack of infrastructure and human capacity are significant limitations though the establishment of the African Animal Breeders' Network is a crucial step toward building the necessary human capacity (Burrow et al., 2021). Genotype by environment interactions must also be considered when importing external small ruminant genetic resources as breeding strategies that involve the introduction of animals from more temperate environments have had varying levels of success (Peacock et al., 2011).

6.2 Opportunities

Despite these challenges, several opportunities exist. First, advances in genotyping technologies have reduced costs making genomic selection more accessible. Second, regional collaboration through organizations such as the African Union's Interafrican Bureau for Animal Resources (AU-IBAR) and the International Livestock Research Institute (ILRI) can facilitate sharing of reference populations and expertise. Third, growing demand for goat meat and milk in urban markets provides economic incentives for genetic improvement. Fourth, climate change adaptation strategies increasingly recognize the role of indigenous livestock genetic resources (Mrode et al., 2018; Haile et al., 2020b). Single nucleotide polymorphisms (SNP) technologies to determine breed composition and promote best genotypes for different production systems are also available (Ojango et al., 2023). The significant role of national governments, international organizations and research organizations such as ILRI and CTLGH has been instrumental in genetically improving small ruminants for increased milk or meat production through specific genetic improvement programs (Mrode et al., 2018).

7. Conclusion

Indigenous goats are key contributors to livelihoods in Kenya's ASAL regions where they provide resilience against climate variability and economic instability. However, their productivity remains far below potential due to limited genetic improvement efforts. Evidence from published studies across Africa and beyond demonstrates that successful improvement depends on establishing clear breeding objectives, accurate genetic evaluation and sustainable dissemination systems. While nucleus breeding programs offer rapid genetic gains, their operational complexity limits their suitability in ASAL regions. Community-based breeding programs present the most feasible approach enabling inclusive participation, preservation of adaptive traits and alignment with local production systems. Evidence from Ethiopia, Malawi, Uganda and Kenya demonstrates that CBBPs can achieve measurable genetic gains and socioeconomic benefits. Integrating genomic selection into CBBPs can substantially accelerate genetic gain even in the absence of comprehensive pedigree records. Genomic tools can assess genetic diversity, improve animal genetics, trace phylogenetic relationships and study geographical distribution and origins (Mrode et al., 2018). The availability of genomic data can facilitate the implementation of GBLUP using genomic relationship matrices, determine breed composition and admixture in the absence of pedigree records, and provide a platform to design mating schemes that optimize productivity and adaptability (Mrode et al., 2018). For long-term success, investments are required in farmer capacity building, recording systems, accessible genotyping technologies and supportive national breeding policies. By combining modern genomic technologies with farmer-led breeding structures, Kenya can significantly enhance indigenous goat productivity while safeguarding the adaptive traits that underpin their resilience in ASAL ecosystems.

References

- [1] Ademosun, A. A. (2003). Constraints and prospects for small ruminant production in Africa. In *Proceedings of the International Workshop on Small Ruminant Production*. ILCA, Addis Ababa, Ethiopia.
- [2] Amankwah, K., Sarpong, D. B., & Karbo, N. (2012). Small ruminant production systems in northern Ghana: Opportunities and challenges for productivity improvement. *African Journal of Agricultural Research*, 7(17), 2561–2571.
- [3] Baker, R. L., & Rege, J. E. O. (1994). Genetic resistance to diseases and other stresses in improvement of ruminant livestock in the tropics. *Proceedings of the 5th World Congress on Genetics Applied to Livestock Production*, 20, 405–412.
- [4] Bekman, H., & van Arendonk, J. A. M. (1993). Derivation of economic values for dairy cattle breeding goals: A comparison of methods. *Livestock Production Science*, 37(3), 173–193.
- [5] Bett, R. C., Kosgey, I. S., Kahi, A. K., & Peters, K. J. (2009). Growth performance of indigenous goats in Kenya. *Livestock Research for Rural Development*, 21(2).
- [6] Birhanie, M., Haile, A., Gizaw, S., & Getachew, T. (2018). Community-based breeding programs for Abergelle goats in Ethiopia. *Livestock Research for Rural Development*, 30(4).
- [7] Biscarini, F., Nicolazzi, E. L., Alessandra, S., Alessio, B., Ajmone Marsan, P., & Gandini, G. (2015). Genomic selection in local sheep and goat breeds: Principles, applications and perspectives. *Small Ruminant Research*, 125, 34–42.
- [8] Burrow, H. M., Mrode, R., & Okeyo, A. M. (2021). African Animal Breeders' Network: Building capacity for genetic improvement in Africa. *Animal Frontiers*, 11(4), 5–7.
- [9] Carillier-Jacquin, C., Larroque, H., & Robert-Granié, C. (2016). Including α s1 casein gene information in genomic evaluations of French dairy goats. *Genetics Selection Evolution*, 48, 54.
- [10] Chenyambuga, S. W., Komwihangilo, D. M., & Jackson, M. (2012). Productivity and management of indigenous goats in Tanzania. *Tropical Animal Health and Production*, 44(6), 1239–1248.

- [11] de Roos, A. P. W., Hayes, B. J., Spelman, R. J., & Goddard, M. E. (2011). Linkage disequilibrium and persistence of phase in Holstein-Friesian, Jersey and Angus cattle. *Genetics*, 179(3), 1503–1512.
- [12] Dekkers, J. C. M. (2004). Commercial application of marker- and gene-assisted selection in livestock: Strategies and lessons. *Journal of Animal Science*, 82(E-Suppl), E313–E328.
- [13] Devendra, C. (2010). Small ruminants: Imperatives for productivity enhancement, improved livelihoods and rural growth – A review. *Asian-Australasian Journal of Animal Sciences*, 14(10), 1483–1496.
- [14] Escareño, L., Salinas-González, H., Wurzinger, M., Pastor, F., & Iñiguez, L. (2012). Dairy goat production systems: Status quo, perspectives and challenges. *Tropical Animal Health and Production*, 45(1), 17–34.
- [15] FAO. (2010). *Animal genetic resources management in Kenya's National Livestock Policy*. In: The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture. FAO.
- [16] FAO. (2015). *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture*. FAO Commission on Genetic Resources for Food and Agriculture.
- [17] Getachew, T., Haile, A., Wurzinger, M., & Rischkowsky, B. (2022). Modeling pastoral goat community-based breeding programs: Optimization of selection intensity and mating structure. *Animal*, 16(8), 100602.
- [18] Getahun, L., Haile, A., Abegaz, S., & Tibbo, M. (2005). Technical and economic performance of community-based goat breeding programs in Ethiopia. *Livestock Research for Rural Development*, 17(3).
- [19] Githui, E. K., Kibegwa, F. M., Kamau, J. M., Mutura, S. K., Okwany, Z. A., Ngigi, D. M., & Mwangi, E. W. (2016). Genetic relationships of indigenous goats reared by pastoralists in Kenya based on mitochondria D-loop sequence. *Animal Genetic Resources*, 59, 73–81.
- [20] Gizaw, S., Getachew, T., Edea, Z., Haile, A., Rischkowsky, B., & Mwai, O. (2013). Characterization of indigenous breeding strategies of the sheep farming communities of Ethiopia: A basis for designing community-based breeding programs. *ICARDA Working Paper*.
- [21] Goddard, M. E., & Hayes, B. J. (2007). Genomic selection. *Journal of Animal Breeding and Genetics*, 124(6), 323–330.
- [22] Haile, A., Getachew, T., Mirkena, T., Duguma, G., Gizaw, S., Wurzinger, M., Soelkner, J., Mwai, O., Dessie, T., Abebe, A., Abate, Z., Jembere, T., Rekik, M., Lobo, R. N. B., Mwacharo, J. M., Terfa, Z. G., Kassie, G. T., Mueller, J. P., & Rischkowsky, B. (2020a). Community-based sheep breeding programs generated substantial genetic gains and socioeconomic benefits. *Animal*, 14(7), 1362–1370.
- [23] Haile, A., Getahun, L., Mirkena, T., Duguma, G., Abebe, G., Rekik, M., & Rischkowsky, B. (2011). Preliminary results of community-based sheep and goat breeding programs in Ethiopia. *Livestock Research for Rural Development*, 23(9).
- [24] Haile, A., Gizaw, S., Getachew, T., Mueller, J. P., Amer, P., Rekik, M., & Rischkowsky, B. (2019). Community-based breeding programmes are a viable solution for sheep and goat genetic improvement in developing countries. *Animal Frontiers*, 9(4), 23–30.
- [25] Haile, A., Khan, M. A., Yadeta, D., & Rischkowsky, B. (2020b). Opportunities for implementing genomic selection in small ruminant breeding programs in developing countries. *Animal Frontiers*, 10(4), 33–39.
- [26] Hayes, B. J., Bowman, P. J., Chamberlain, A. J., & Goddard, M. E. (2009). Genomic selection in dairy cattle: Progress and challenges. *Journal of Dairy Science*, 92(2), 433–443.
- [27] Heidaritabar, M. (2016). Applications and limitations of marker-assisted selection in livestock breeding programs. *Iranian Journal of Applied Animal Science*, 6(4), 699–708.
- [28] Kahi, A. K., Wasike, C. B., & Rewe, T. O. (2006). Beef production in the arid and semi-arid lands of Kenya: Constraints and prospects for research and development. *Outlook on Agriculture*, 35(3), 217–225.
- [29] Kariuki, C. M., van Arendonk, J. A. M., Kahi, A. K., & Komen, H. (2017). Multiple criteria decision-making process to derive consensus desired genetic gains for a dairy cattle breeding objective for diverse production systems. *Journal of Dairy Science*, 100(6), 4671–4682.
- [30] Kaumbata, W., Banda, L., Mészáros, G., Gondwe, T., Woodward-Greene, M. J., Rosen, B. D., & Wurzinger, M. (2021). Community-based breeding programs for small ruminants in Malawi and Uganda: Lessons learned and prospects. *Frontiers in Animal Science*, 2, 678905.
- [31] Kichamu, N., Wanjala, G., Csiszter, L. T., Strausz, P., Astuti, P. K., Bagi, Z., & Kusza, S. (2024). Assessing the population structure and genetic variability of Kenyan native goats under extensive production system. *Scientific Reports*, 14(1), 16284.
- [32] KNBS. (2019). *Kenya Population and Housing Census Analytical Report on Population Dynamics*. Kenya National Bureau of Statistics.
- [33] Kosgey, I. S. (2004). *Breeding objectives and breeding strategies for small ruminants in the tropics*. PhD Thesis, Wageningen University, The Netherlands.
- [34] Kosgey, I. S., Baker, R. L., Udo, H. M. J., & Van Arendonk, J. A. M. (2006). Genetic improvement of small ruminants in low-input, smallholder production systems: Technical and infrastructural issues. *Small Ruminant Research*, 61(1), 35–45.
- [35] Lwiza, F., Mwai, O., Ojango, J. M. K., & Mrode, R. (2024). Community-based breeding programs for indigenous goats in Uganda: Economic returns and governance. *Tropical Animal Health and Production*, 56, 245.
- [36] Meuwissen, T. H. E., Hayes, B. J., & Goddard, M. E. (2001). Prediction of total genetic value using genome-wide dense marker maps. *Genetics*, 157(4), 1819–1829.
- [37] Meuwissen, T., Hayes, B., & Goddard, M. (2016). Genomic selection: A paradigm shift in animal breeding. *Animal Frontiers*, 6(1), 6–14.
- [38] Mrode, R. A. (2014). *Linear models for the prediction of animal breeding values* (3rd ed.). CABI Publishing.
- [39] Mrode, R., Mekuriaw, G., Mwacharo, J. M., & Djikeng, A. (2018). The potential for the application of genomic selection for small ruminants in developing countries. *Animal Frontiers*, 8(4), 33–39.

- [40] Mueller, J. P., Rischkowsky, B., Haile, A., Valle Zárate, A., Tibbo, M., & Iñiguez, L. (2006). Community-based livestock breeding programmes: Essential elements and implementation. In *Proceedings of the 8th World Congress on Genetics Applied to Livestock Production (WCGALP)*, Belo Horizonte, Brazil.
- [41] Mueller, J. P., Rischkowsky, B., Haile, A., Valle-Zárate, A., Tibbo, M., & Iñiguez, L. (2015). Community-based livestock breeding programmes: Essential elements and implementation. *Animal Frontiers*, 5(2), 12–17.
- [42] Mugambi, J. N. (2006). Evaluation of growth performance of the Kenya dual purpose goat composites from birth to yearling. *University of Nairobi*.
- [43] Ncube, K. T., Nephawe, K. A., Mpofu, T. J., Monareng, N. J., Mofokeng, M. M., & Mtileni, B. (2025). Genomic advancements in assessing growth performance, meat quality, and carcass characteristics of goats in sub-Saharan Africa: A systematic review. *International Journal of Molecular Sciences*, 26(5), 2323.
- [44] Ng'ang'ombe, A. N., Banda, J. W., & Kamwanja, L. A. (2011). Small ruminant production under traditional management systems in Malawi: Implications for improved breeding schemes. *Livestock Research for Rural Development*, 23(12).
- [45] Ng'ang'ombe, B. A., Waineina, R. W., Ngeno, K., Okeno, T. O., & Ilatsia, E. D. (2019). Assessing the population structure and genetic variability of Kenyan native goats under extensive production system. *Peer-reviewed article*.
- [46] Ojango, J. M. K., Gitau, J., Ndiwa, N., Recha, J. W., Gachora, J., & Muigai, A. W. T. (2023). Integration and adoption of climate resilient management practices for enhanced productivity of sheep and goats in pastoral communities of Northern Kenya. *Pastoralism*, 13, 14.
- [47] Ojango, J. M. K., Oyieng, E., Gitau, J. W., Ndiwa, N., Gachora, J., & Muigai, A. W. T. (2024). Adapting climate-smart breeding practices for small ruminants in pastoral communities of Kenya. *Joint International Congress on Animal Science*, Lyon, France.
- [48] Ojango, J. M. K., Pollott, G. E., & Okeyo, A. M. (2011). Improving the productivity of indigenous goats in Kenya: A review. *Animal Genetic Resources*, 48, 45–54.
- [49] Ojango, J. M. K., et al. (2004). Evaluation of breeding values in small ruminants in East Africa. *Small Ruminant Research*, 52, 123–134.
- [50] Ojango, J. M. K., et al. (2010). FARM-Africa farmer-based breeding strategy for goat improvement. In *Proceedings of the 9th World Congress on Genetics Applied to Livestock Production*, Leipzig, Germany.
- [51] Peacock, C. (2005). Goats – A pathway out of poverty. *Small Ruminant Research*, 60, 179–186.
- [52] Peacock, C., et al. (2011). FARM-Africa goat improvement programme: Lessons from 20 years of implementation. *FARM-Africa Working Paper*.
- [53] Rege, J. E. O., et al. (2001). Open nucleus breeding schemes in Africa: Small ruminant case studies. *Livestock Production Science*, 71, 159–171.
- [54] Rewe, T. O., et al. (2004). Nucleus breeding programs in small ruminants: Strategies and challenges. *Animal Genetic Resources*, 34, 21–32.
- [55] Schoof, J. T., & Luick, J. R. (2018). Pastoral mobility and rangeland management in arid and semi-arid regions. *Journal of Arid Environments*, 155, 1–9.
- [56] Turkana County Government. (2026). Turkana Pastoralists Launch Community-Led Program to Improve Local Goat Breeds. Retrieved from <https://turkana.go.ke>
- [57] Wiggans, G. R., Cole, J. B., Hubbard, S. M., & Sonstegard, T. S. (2017). Genomic selection in dairy cattle: The USDA experience. *Annual Review of Animal Biosciences*, 5, 309–327.
- [58] Wurzinger, M., Sölkner, J., & Iñiguez, L. (2011). Important aspects and limitations in considering community-based breeding programs for low-input smallholder livestock systems. *Animal*, 5(3), 436–446.