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Review

Balancing Tradition and Innovation: A 5-Year Review of Modern Approaches to Livestock Breed Conservation

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Abstract

As severe selection and declining population numbers in many breeds have resulted in losses in the worldwide livestock genetic biodiversity, human concern about the situation of genetic variety in livestock breeds and their conservation has grown. In this context, genomic techniques now allow for more exact monitoring of adaptive traits and inbreeding, while reproductive techniques such as somatic cell nuclear transfer and IVF (In Vitro Fertilization) help to preserve and recover rare genetic lines. AI-powered (Artifficial Inteligence) risk assessment models and digital herdbooks contribute to data-driven reproductive strategies, particularly in smallholder settings. Nonetheless, these advances face persistent hurdles, including a lack of legislative frameworks, high costs, limited accessibility in low-resource settings, and unresolved ethical problems. The findings highlight the importance of a balanced, interdisciplinary strategy that combines new biotechnologies with traditional knowledge, collaborative practices, and strong policy to assist in preserving the long-term viability of livestock genetic resources. This review intends to assess modern and traditional methods for the preservation of livestock breeds, analyzing references published between 2019 and the present.

Keywords: conservation strategies; genomic technologies; cryopreservation; reproductive biotechnologies; digital traceability systems

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1. Introduction

Approximately one-third of the global population relies on livestock for a living. Around one-third of domestic animal breeds are at risk in Europe and the Caucasus, while 16% of mammalian varieties in North America face similar threats. These are the two locations with the most specialized livestock sectors, characterized by production dominated by a limited number of breeds [1]. Nonetheless, significant ambiguity persists over the true status of breed endangerment as recent population data is lacking for numerous places worldwide. The decline in breed diversity is expected to be far more acute, given 58% of global breeds possess an indeterminate risk status [2]. The significance of this threat is underscored by the potential of endangered breeds and their genetic material to address issues associated with diverse diseases, in addition to the challenges posed by climate change, including extreme weather events, escalating water scarcity, and fluctuations in feed availability [3,4].

Historically, the conservation of livestock has been underpinned by two principal methodologies: in situ and ex situ approaches. In situ conservation entails the preservation of breeds within their native habitats, thereby sustaining their ecological and genetic contexts. This approach facilitates the acclimatization of breeds to specific environmental contexts while simultaneously involving local communities in sustainable methodologies. Conversely, ex situ conservation methods, encompassing cryopreservation and controlled breeding practices, function as a protective measure against species extinction; however, they frequently exhibit deficiencies in facilitating the genetic exchange essential for ensuring resilience [2,5–14].

In this direction, the effective population size (Ne) represents a critical parameter in the field of evolutionary biology, as it is associated with the long-term viability of species. Consequently, Ne holds significant interest for conservation geneticists, while also being highly pertinent to policymakers, managers, and conservation practitioners. Quantitative genetic theory predicts that Ne is positively correlated with the extent of additive genetic variation. Furthermore, the ability of a population to respond to selection is contingent upon the degree of genetic variation present for the traits subject to selection. Nonetheless, the relationship among Ne, genetic variation, and evolutionary potential is intricate and influenced by various factors, including the quantity of loci associated with a trait, the existence of dominance or epistasis, and the impact of novel mutations, as well as the mode and intensity of selection. While the implications of small effective population size in natural populations and domestic breeds exhibit certain distinctions, valuable insights can be derived from the integration of knowledge across these varied domains. Investigations into the genetic dynamics of small and fragmented natural populations, including island populations and those nearing extinction, yield insights and frameworks that may be relevant for the management of small domestic populations. This encompasses the implementation of genetic rescue to enhance the adaptive capacity of small populations, as well as the utilization of genotype-by-environment interactions to guarantee that populations sustain elevated fitness levels across varying environments. Conversely, the efforts of animal and plant breeders have demonstrated the efficacy of utilizing comprehensive pedigrees, extensive phenotypic data, substantial sample sizes, and advanced reproductive technologies to address genetic challenges present in small populations. Data derived from pedigrees is currently being used in natural populations of avian and mammalian species, wherein individuals can be monitored and traced across successive generations. Furthermore, there is the potential to implement additional methodologies from livestock management within small and endangered natural populations [15–19].

In this regard, this review aims to analyze how the integration of contemporary genomic techniques into established conservation strategies can enhance the effectiveness of breeding initiatives aimed at preserving and improving genetic diversity in livestock. Focusing on literature published over the past five years (2019–present), this review captures a period of accelerated innovation in genomic tools, reproductive technologies, and digital systems that have significantly reshaped conservation priorities and methodologies. Additionally, it seeks to identify contemporary trends, assess their efficacy, and suggest comprehensive strategies for future conservation initiatives.

2. Traditional Conservation Methods

In situ livestock breed conservation includes a variety of community-based and on-farm programs that work to protect local genetic diversity while promoting sustainable farming methods (Table 1). These methods acknowledge the significance of indigenous livestock breeds, which are frequently more suited to local conditions than the high-yield types preferred in modern agriculture. Community involvement is essential for the

success of these conservation initiatives, as local knowledge and practices can improve the sustainability of livestock management, hence reinforcing the socio-cultural importance of traditional breeds [6,20].

One major benefit of in situ conservation is that it helps keep genetic variety in local breeds. Farmers who take part in these initiatives generally find that diversifying their livestock makes it more resilient to changes in the market and the weather, which improves their economic stability and food security [6]. Local breeds can also have specific features that help them adapt to diseases and environmental challenges, which makes them very important in the context of climate change [6].

In this regard, Velado-Alonso et al. (2020) [21] provides significant insights into the advantages and disadvantages of in situ cattle breed conservation approaches within their broader ecological framework. This study shows that one of the benefits of in situ conservation is the positive link between the richness of local cattle breeds and the diversity of wild vertebrate species. This association indicates that areas with a variety of livestock may also support animal diversity, possibly due to the conservation of traditional agricultural methods that sustain ecosystems favorable to both livestock and wildlife [21]. The report also points out the challenges that come with in situ conservation measures. The different relationships between various cattle breeds and wildlife species richness highlight the necessity for customized conservation strategies. For instance, cattle breeds were observed to have a positive relationship with wildlife, but sheep breeds exhibited negative interactions [21]. This difference shows that not all ways of protecting livestock are equally good for the environment, and that taking care of some breeds the wrong way could unintentionally hurt wildlife.

In situ conservation can help biodiversity, but it needs to be performed with an understanding of the individual environmental conditions and how different livestock breeds interact with their ecosystems [21]. So, to obtain the most benefits for biodiversity, good conservation planning should include both agricultural and ecological points of view.

Moreover, many factors affect the acceptance of conservation techniques including financial incentives and farmers' participation in program design [22]. Conservation programs are more likely to be adopted by farmers when they perceive them as improving their long-term viability and environmental stewardship [23]. Furthermore, including farmers' points of view into the formulation of conservation strategies can help to greatly increase the efficacy of programs, thus encouraging a feeling of responsibility and dedication among the engaged parties [22].

Table 1. In situ livestock breeds conservation strategies.

Methodology	Breeds Investigated	Outcome Measured	Main Findings	Ref.
- Maraichine Association's new system for population control - Mating plans with sociological input - Farmer surveys (2004, 2018, 2019)	Maraichine cattle, Charolais cattle	- Ease of calving (percentage of births requiring no assistance) - Calving rate (percentage) - Milk production (kg/day) - Carcass characteristics (EUROP classification) - Disease resistance (veterinary expenses per livestock unit per year, EUR)	- Population grew from 8 to 1666 in 30 years; breeders from 3 to 127 - Inbreeding rate kept at 3.9% (2015) - Veal meat sales yielded 45% higher margin than weanlings	[24]
Three-step strategy (Discover, Secure, Sustain): - Identify candidate populations via historical, phenotypic, and genetic analysis - Apply rescue and breeding protocols to recover genetic variation - Stimulate market demand to ensure long-term sustainability	- American Spanish goats - Texas Longhorn cattle - Navajo Churro sheep - Pineywoods cattle - Randall Lineback cattle - Heritage turkeys - Santa Cruz Island sheep	- Recognition and validation of breeds as repeatable genomic packages - Securing genetic variation through rescue protocols - Maintaining production potential and genetic structure - Sustaining market demand for breeds and their products	- Livestock breeds should be viewed as repeatable genomic packages with predictable performance - The Discover–Secure–Sustain model effectively protects livestock populations - Successful conservation requires attention to biological, genetic, and cultural factors	[25]
Understanding livestock breeds genetic adaptation to environmental conditions in order to update in situ conservation strategies by landscape genetics.	- Rathi, Siri cattle breeds - Indian sheep breeds - Goat, chicken, swine, yak: Various breeds	Gene flow, impact of global change on genetic patterns, adaptive pattern of species at different geo-climatic conditions, functional connectivity, genetic connectivity	- 94% increase in hatching rate by introducing new genes - More males and fewer stillbirths in Scandinavian adder population - Improved survival in migrant and inbreeding treatment groups vs. control (no exact values)	[26]
- Semen cryopreservation and spermatological diagnostics - Intraspecies cloning via somatic cell nuclear transfer (SCNT) - Cryobanking of germplasm (semen and embryos) - Development of genetically stable primary cell cultures - Generation of SCNT embryos using somatic cells	- White-backed, Polish Red, Polish Black and White, Polish Red and White cattle breeds - Puławska, Złotnicka Spotted pig breeds	Efficiency of cryopreservation methods for semen and embryos; Success rates of generating embryos through SCNT to the blastocyst stage (e.g., 30.1% for Polish Red cattle, 34.1% for Puławska pigs, 27.9% for Złotnicka Spotted pigs)	- 80.9% sperm motility, 56.7% viability, 60.1% acrosomal integrity with BHT extender - 87% farrowing rate, 11 piglets per litter - NT embryo efficiency: 30.1% (bovine), 34.1% (Puławska pigs), 27.9% (Złotnicka Spotted pigs)	[27]

Table 1. *Cont.*

Methodology	Breeds Investigated	Outcome Measured	Main Findings	Ref.
In situ conservation of livestock breeds in Slovakia is primarily based on animal breeding in natural conditions without limitations to breed improvement.	- Slovak Pinzgau cattle - Valachian sheep - Improved Valachian and Tsigai sheep - Askanian Merino sheep - Lipitsa, Shagya Arab, Hutsul, Furioso, Slovak Sport Pony horses - Noric of Murany horses - Nonius horses	Population size and number of registered purebred females	- Slovak Pinzgau cows declined from 2500 (2003) to 1600 (2006), then rose to 2000 (2010) - Valachian sheep increased from 50 (2003) to 907 (2020) - Improved Valachian and Tsigai sheep declined until 2016, then stabilized - Askanian Merino sheep maintained a stable population with one registered breeder - Lipitsa, Shagya Arab, Hutsul, Furioso, and Slovak Sport Pony horses saw an increase in purebred females since 2003 - Norik of Murany horses declined; Nonius horses remain at low levels - The open conservation system allows adding new breeds and subsidies support stability, but the lack of national legislation remains a key issue	[28]

Ex situ conservation is similarly important, particularly in relation to techniques like gene banking and cryopreservation, which are essential instruments for maintaining genetic variety outside of conventional agricultural settings (Table 2). Cryobanking genetic materials helps keep genetic variety alive, which opens up new breeding opportunities that might not have been possible otherwise [29,30]. These methods are very significant for breeds that are in danger of going extinct because of commercial pressures that favor fewer, more productive breeds [30]. Furthermore, ex situ methods can be structured to enhance in situ initiatives, providing a more comprehensive approach to conservation [31].

In this regard, Yang et al. (2021) [32] discussed about how cryopreservation can help maintain genetic variety and gene banks for breeding programs. They highlighted how important it is for the long-term health of agriculture [32]. Huang et al. (2019) support this idea by saying that improvements in cryopreservation methods have made it easier for gametes and embryos to survive in livestock, especially in cattle, sheep, and pigs [33].

Additionally, improvements in cryopreservation have made it possible to preserve embryos successfully. Elango et al. (2021) researched the dynamics of mitochondrial membrane potential and DNA damage during the cryopreservation of cattle and buffalo bull spermatozoa, highlighting the significance of cellular responses in enhancing recovery rates [34]. Dhali et al. (2019) also talk about successful embryo cryopreservation procedures that have been employed in several types of mammals, such as livestock [35]. Conversely, research demonstrates that cryopreservation may impact the genetic integrity of frozen materials. In this regard, Nikitkina et al. (2022) performed a genome-wide association analysis that identified unique genomic variants influencing frozen-thawed sperm motility in stallions, indicating that genetic factors significantly impact the efficacy of cryopreservation [36]. Zhu et al. (2019) stated that cooling, freezing, and thawing boar sperm might cause oxidative stress, which can affect the quality of the sperm [37]. Similar findings by Ebenezer Samuel King et al. (2022) underscore that the reproductive potential of cryopreserved sperm, although beneficial for artificial insemination, may not equate to that of fresh sperm due to cellular damage incurred during the cryopreservation procedure [38]. Moreover, research indicates that several factors, including the frequency of semen collection and environmental conditions, can influence the quality of cryopreserved semen. For instance, Pimprasert et al. (2023) shows that seasonal changes have a big effect on the quality of both fresh and frozen semen in Thai native roosters [39]. To keep sperm alive after thawing, it is important to make sure that the conditions for collecting and processing it are as good as possible [40].

Moreover, artificial insemination and intra-cytoplasmic sperm injection (ICSI) are two examples of assisted reproductive technologies (ARTs) that rely significantly on cryopreserved genetic resources to improve the breeding efficiency of cattle. Technologies continue to evolve, as evidenced by the research conducted by Rather et al., which examines the socio-economic aspects influencing the adoption of artificial insemination processes in livestock management [41].

On the other hand, ex situ procedures have certain benefits, but they also have some drawbacks. For example, they are expensive because they require advanced technologies and specialized workers, which makes them less accessible to communities, especially in poor areas [29]. Furthermore, dependence on artificial reproduction techniques (ARTs) may alienate animals from their indigenous ecological surroundings, thus reducing the adaptive capacity of breeds over time [31].

Table 2. Ex situ livestock breeds conservation strategies.

Methodology	Breeds Investigated	Outcome Measured	Main Findings	Ref.
- Development of bioreservoirs via cryogenic and lyophilization methods for ex situ conservation - Use of ARTs such as SCNT and IVF - Cryopreservation and lyophilization of somatic/stem cells and germplasm (sperm, oocytes, embryos) - Establishment of ex vivo-expanded permanent cell lines from tissue biopsies - Research on factors influencing proliferation and genetic stability of donor cell lines - Application of preserved semen in ARTs, especially for in vitro embryo production	- Merino, Blackhead, Polish Heath, Olkuska sheep - Polish Red cattle - Carpathian goats - Złotnicka Spotted, Puławska, Złotnicka White pigs	- Blastocyst formation rate. - Efficiency of SCNT-based cloning. - Number of somatic and stem cell lines. - Number of germplasm-based biological materials	- Bioreservoirs for ex situ conservation developed using cryopreservation and lyophilization - SCNT success depends on somatic/stem cell line quality - Preserved semen supports ARTs and genetic resource conservation	[42]
- Semen cryopreservation - Spermatological diagnostics - Intraspecies cloning by SCNT - Establishment and cryopreservation of genetically stable somatic cell lines - Generation of nuclear-transferred embryos	- White-backed, Polish Red, Polish Black and White, Polish Red and White cattle - Puławska, Złotnicka Spotted pigs	- Ne - Efficiency of generating nuclear-transferred embryos to reach the blastocyst stage (%) - Cryosurvival rate (%)	- Reproductive biotechnologies like semen cryopreservation and SCNT are key to conserving endangered Polish breeds - Efficient cryopreservation protocols developed, especially for cattle - Genetically stable somatic cell lines established for Polish Red cattle, Puławska, and Złotnicka Spotted pigs	[42]
- Development of conservation management surveys Breed characterization and conservation through consortia - Efficient resource use via international cooperation (e.g., CONBIAND network) Systematic coordination by national committees - Use of both conventional and modern tools (e.g., multi-criteria analysis) - Proactive emergency response via national alert systems and inventory coordination - Interdisciplinary approach integrating genetics, economics, and ecology	- Pigs (European Gene Banking Project, PIGBIODIV 2) - Cattle (European Cattle Genetic Diversity Consortium, BIOBOVIS) - Small ruminants (ECONOGENE, BIOGOAT) - Horses (Equine Genetic Diversity Consortium, BIOHORSE) - Chickens (AVIANDIV) - Donkeys (BIODONKEY) - Turkeys (BIOTURKEY) - Guinea pigs (BIOCUY)	- Maintenance of domestic animal diversity - Conservation of breeds - Maximization of intrapopulation genetic variability - Monitoring and reporting of breed status - Establishment and management of germplasm banks - Establishment and management of ex situ conservation centers	- National committees for domestic animal genetic resources are recommended to organize conservation efforts. - The CONBIAND network is a model for efficient conservation in low-resource settings through international cooperation. - National committees coordinate conservation activities, including alert systems and ex situ conservation centers.	[43]

Table 2. *Cont.*

Methodology	Breeds Investigated	Outcome Measured	Main Findings	Ref.
- Multi-period chance-constrained model for optimizing endangered breed collections - Uses stochastic linear programming to minimize costs under cryotank limits and in situ uncertainties - Applied to semen collection, implemented in AIMMS 2018—Modeling Guide—Integer Programming Tricks and solved with IBM ILOG CPLEX Optimization Studio (v12.8; IBM, Armonk, NY, USA).	- Cattle: 8 non-endangered, 31 endangered - Sheep: 36 non-endangered, 8 endangered - Goats: 20 non-endangered, 3 endangered - Pigs: 3 non-endangered, 12 endangered - Chicken: 1 non-endangered, 16 endangered - Equine (horse and donkey): 1 non-endangered, 14 endangered	- Total cost of all gene banks over the planned period. - Sensitivity analysis of 'acceptable level of risk' versus total collection costs.	- A model was developed to optimize collection sites, timing, and quantities for endangered livestock breeds at minimal cost - Based on data from 18 gene banks, it links ex situ collection costs to in situ extinction risk - Strategic use of local gene banks and a national backup can reduce extinction risk cost-effectively	[30]

As previously discussed, in situ and ex situ conservation strategies both have their own benefits and drawbacks (Figure 1). In situ conservation promotes natural adaptation and cultural significance, which are vital for sustainable livestock management, whereas ex situ approaches offer a secure approach to protecting genetic variety from extinction. On the other hand, Li et al. (2024) noted that the Gushi breed had greater genetic diversity in in situ conservation compared to ex situ, with GS2 displaying a higher level of inbreeding [44]. Furthermore, the Xichuan black-bone breed exhibited no significant alteration in genetic diversity between ex situ and in situ conservation methodologies [44]. Similar findings were noted by Zhang et al. (2020) in their study on domestic Chinese chicken breeds [45].

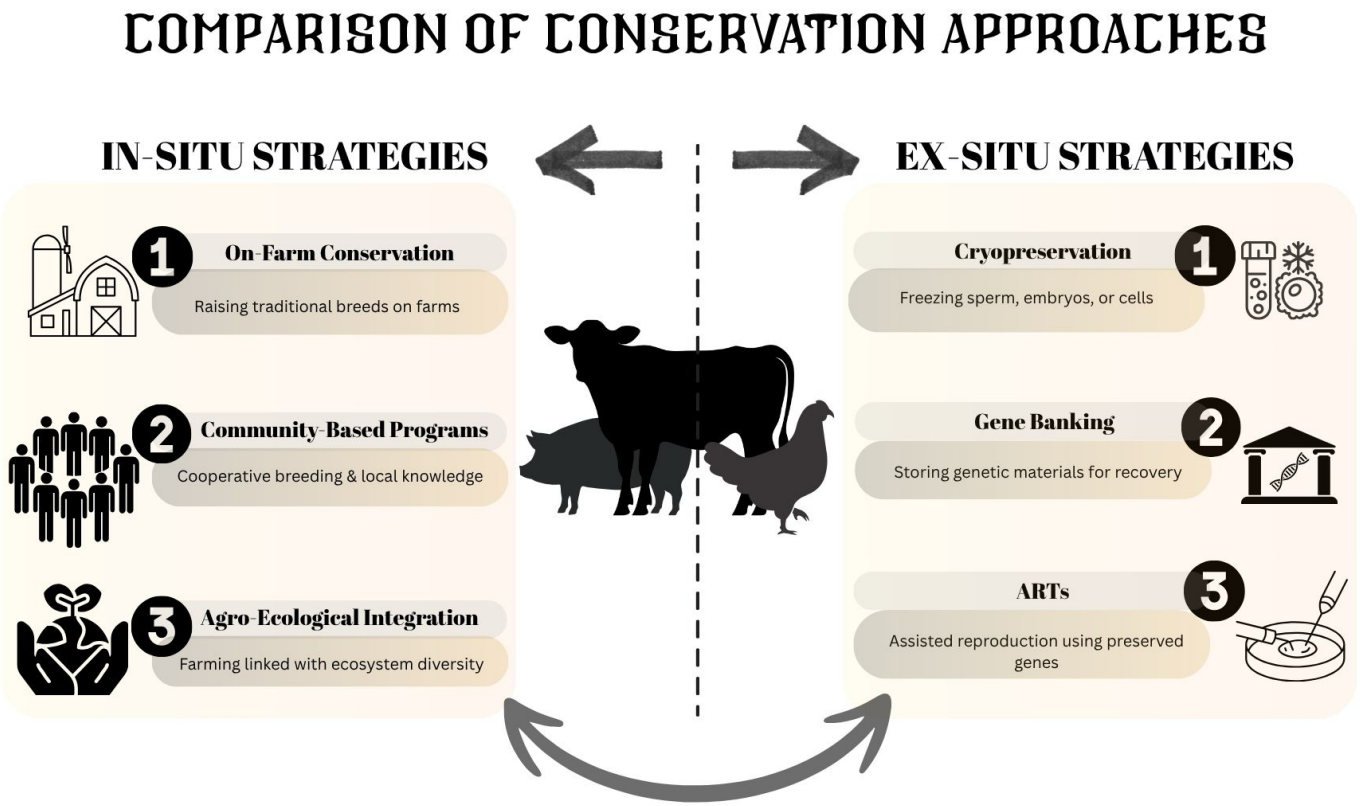


Figure 1. In situ and ex situ strategies for livestock breed conservation (original via www.canva.com).

Institutional and political support is very important for both in situ and ex situ initiatives to protect livestock. Policies that encourage the preservation of local breeds and provide financing for community-based programs can greatly increase the involvement of farmers and livestock keepers. A strong legal framework that focuses on protecting genetic resources can help different groups cooperate together, which will help them manage livestock variety in a more efficient manner [6].

3. Modern Approaches in Livestock Breed Conservation Methods

3.1. Genomic Selection and Genomic Diversity Monitoring

One of the modern approaches in livestock breed conservation is genomic selection (Figure 2). This strategy uses genomic data like single nucleotide polymorphisms (SNPs) to enhance breeding decisions. This method allows the selection of the animals based on their genetic potential for desirable traits, like fast development, disease resistance, and adaptability to climate variations. In this context, Arya et al. (2024) examined the application of genomic analysis to identify genetic markers linked to attributes such as heat tolerance and disease resistance in livestock [46]. By incorporating these markers into breeding programs, this strategy promoted the sustainability of livestock production in

the face of climate change. Eusebi et al. (2019) also underscore the application of genomic techniques for the efficient conservation of livestock breed variety [1]. In the past, pedigree data were used to determine how genetically diverse a breed was [1]. Now, genomic markers give us a more detailed picture of a breed's genetic status, which helps us choose which breeds to protect [47]. This information helps conservation efforts focus on keeping genetic variety, which is very important for the flexibility and resilience of cattle herds.

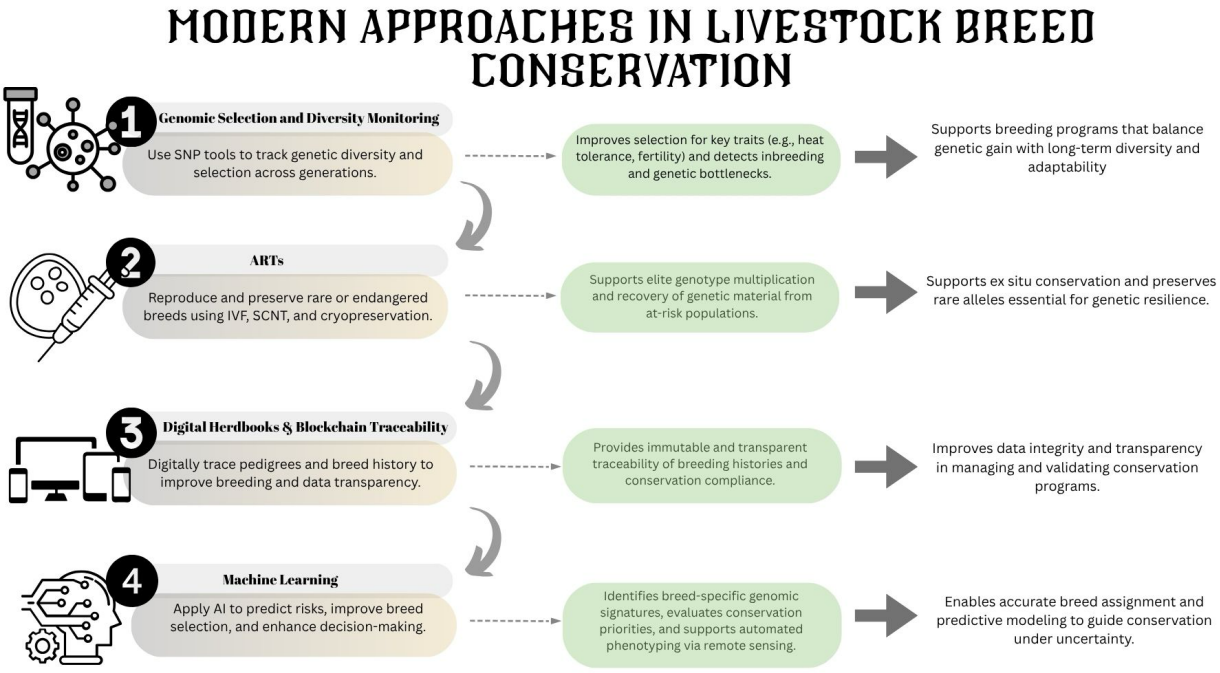


Figure 2. Modern approaches in livestock breed conservation (original via www.canva.com).

Genomic diversity monitoring additionally involves examining the genetic differences between and within groups of animals to understand more about their health and adaptation. It can reveal genetic bottlenecks, inbreeding, and potential extinction hazards. In this regard, Biscarini et al. (2020) did a study on Maremmana semi-feral cattle, utilizing both pedigree and genomic data to assess genetic diversity parameters [47]. They explored areas of homozygosity and heterozygosity in the genome. Their research showed that monitoring these genetic parameters is very important for making sure that conservation efforts work [47]. Such assessments can help identify genetic weaknesses and contribute to management methods to limit the risks of inbreeding and genetic erosion. Regarding livestock, Szmatoła et al. (2019) examined runs of homozygosity among eleven cattle breeds in Poland [48]. Their research facilitated the assessment of genomic inbreeding coefficients and pinpointed genetic areas influenced by selective breeding. This form of monitoring is crucial for understanding the impacts of past selection on current genetic diversity and guiding future breeding decisions to maintain genetic health [48].

3.2. Advanced Reproductive Technologies

IVF is a reproductive approach by fertilizing oocytes outside of the animal's body (Figure 2). This provides breeders more control over the breeding process and allows them to select for desirable genetic traits. This strategy is especially helpful for conservation efforts for indigenous breeds that might not be able to reach the population proportions they need. In this direction, Selokar et al. (2019) demonstrated successful IVF application in producing embryos using a buffalo bull's sperm and cloning techniques, highlighting how IVF can aid in the conservation of genetic material from high-performing individuals,

supporting the long-term sustainability of livestock populations [49]. Cloning, especially SCNT, makes it possible to create genetically identical individuals from just one somatic cell. This method has a lot of potential for saving unique and endangered breeds of livestock. In a similar study, Fatira et al. (2019) talked about SCNT as a cloning method that may assist in preserving endangered species, such as cattle breeds, and demonstrated how it can be used to protect species that are about to go extinct [50]. Cloning can efficiently recover valuable genetic lines that may be lost owing to diminishing population sizes by reprogramming somatic cells.

3.3. Digital Herdbooks and Blockchain for Traceability

Digital herdbooks are electronic records that store detailed information about different types of livestock, such as their genealogy, breeding history, health, and genetic traits (Figure 2). These solutions allow for real-time updates and access to data, which makes it easier to manage and protect herds. In this regard, the use of digital herdbook systems in the Scottish agriculture industry has enhanced livestock management. The Scottish National Herdbook assists farmers to document and manage breeding operations and health data for their animals efficiently [51,52].

Blockchain technology is an excellent method to improve traceability in livestock production systems because it is decentralized and cannot be changed. Blockchain allows stakeholders to see reliable and accurate records of cattle movements, pedigree data, and breeding techniques [53]. A study by Kamble et al. (2020) emphasized the utilization of blockchain technology to establish a transparent traceability system in agricultural supply chains [54]. Blockchain improves customer trust and encourages better compliance with conservation practices by making sure that every transaction, from breeding to sale, is documented clearly and unchangeable. The capacity to trace an animal's genetic past and its breeding techniques increases accountability among breeders, helping to the general preservation of genetic variety.

3.4. Machine Learning for Breed Identification and Risk Assessment

Machine learning (ML) algorithms can be employed to analyze genetic data or phenotypic traits to successfully identify and classify different livestock breeds (Figure 2). This capability is especially helpful in the assessment of genetic diversity and the supervision of breeding programs. Gao et al. (2022) employed a random forests algorithm to find certain SNPs in Chinese indigenous pig breeds [55]. The ML algorithm showed a high accuracy rate (over 99%) in assigning individuals to their respective breeds based on these genetic markers [55]. This method helps identify breeds and assists in keeping track of and protecting genetic variation in cattle herds. In another study, Xu et al. (2020) utilized deep learning approaches to improve livestock classification from aerial imagery captured by drones [56]. The study concentrated on the development of a convolutional neural network to precisely identify and categorize various cattle breeds, demonstrating the potential of ML to improve agricultural management methods via remote sensing technologies [56].

ML techniques can also analyze historical and current information to forecast what risks might influence animal breeds and assess their conservation status. In this direction, Lee et al. (2019) used ML methodologies to evaluate growth performance and reproductive parameters in dairy cattle, encompassing estrous and pregnancy rates [57]. By properly integrating this data, they were able to create predictive models that analyze how effectively herds reproduce under different conditions. Moreover, Seo et al. (2021) focused on identifying target chicken populations through ML models utilizing minimum SNPs [58].

While traditional and modern (ex situ and technology-driven) conservation methods have been discussed separately, a direct comparison highlights their complementary roles.

In situ methods are usually less costly and more in line with local traditions, which allows cultural continuity and natural adaptation to specific environments. These strategies are particularly effective in promoting resilience through locally adapted genetic traits and excel in community involvement. Nevertheless, they may encounter challenges in the areas of scalability, precise genetic surveillance, and the preservation of breeds with critically low population sizes. On the other hand, modern approaches like cryopreservation, genomic selection, and digital herdbooks are very accurate, scalable, and easy to trace. Their primary constraints are the high costs of implementation, the complexity of technology, and the limited integration of socio-cultural dimensions. Although they are different, these two methods work very well together: in situ conservation protects the ecological and cultural environment; modern tools improve genetic monitoring, reproductive success, and long-term viability. To optimize breed conservation in the face of evolving environmental and socioeconomic conditions, an integrated strategy that capitalizes on the strengths of both is necessary.

Regarding the worldwide situation, traditional conservation efforts in Europe have frequently used both in situ and ex situ measures for preserving local livestock genetic diversity. CBBPs have been developed as effective options, particularly in smallholder farming settings. Such projects involve local farmers in maintaining and improving the genetic quality of indigenous breeds, creating increased resilience to market pressures and climate variability [59,60].

Furthermore, Europe has devised a variety of legal frameworks and conservation incentives to help preserve native breeds. Conservation programs often provide financial support to farmers to preserve uncommon breeds, such as Alistana-Sanabresa and Maremmana cattle [61,62]. Ex situ technologies, such as cryopreservation of genetic materials, have proven crucial to conserving precious genetic resources and maintaining breed reproduction even in changing conditions [42].

In Asia, cultural practices and values have a significant impact on local livestock conservation. For example, in Mongolia, cultural events such as Naadam, which include horse racing and festivals, help to preserve historic horse breeds [63].

Countries with substantial livestock populations, such as China and India, are implementing ex situ conservation strategies, including the use of reproductive technology to rebalance genetic diversity in endangered breeds. Genomic technologies, for example, are helping to preserve indigenous pig breeds in China by improving genetic mapping and variety [64]. However, these attempts are hampered by the widespread influence of commercial breeding methods, which frequently favor exotic breeds over local variations, endangering traditional livestock systems [65,66].

Traditional conservation approaches in Africa place a strong emphasis on indigenous knowledge systems and community engagement. Many indigenous cow breeds, including the Fulani zebu, are perpetuated through broad pastoralist systems in which herders use their expertise of breed adaptability to environmental conditions [67,68]. CBBPs are gaining popularity, with an emphasis on managing indigenous goat breeds in smallholder settings in Malawi and Uganda, which improves livestock productivity while conserving genetic resources [69].

However, Africa faces significant challenges in livestock conservation due to socioeconomic issues such as war and globalization-related pressures that favor industrial livestock production practices. These challenges cause a reduction in indigenous breeds and livestock knowledge systems, highlighting the crucial need for legislative action to support conservation efforts [70].

In North and South America, the livestock conservation strategies are increasingly combining traditional approaches with modern technology [65,71]. For example, the

United States aims to preserve indigenous heritage breeds like the Old Spot pig and Bourbon Red turkey by promoting genetic variety through community participation and education [62,72].

Furthermore, indigenous populations preserve their cattle breeds using traditional ways that combine features of their culture and environment, promoting conservation based on local practices. However, modernization of agriculture poses a severe threat, driving native breeds to extinction owing to market competition from high-yielding commercial breeds [25,73].

In Oceania, livestock conservation is defined by the incorporation of indigenous knowledge and practices. In Australia and New Zealand, indigenous and imported livestock breeds are protected through community engagement and cultural practices that prioritize sustainability and biodiversity [60,72]. Initiatives to conserve the distinctive genetic resources of local breeds frequently emphasize the ecological benefit they give, which contributes to agrobiodiversity [74].

Effective conservation efforts in Oceania necessitate an awareness of both biological and cultural implications, supporting collaborative initiatives that combine science and traditional management [75].

4. Challenges and Future Directions

Biotechnology has transformed livestock breed conservation by adding novel techniques like gene editing and cloning. But this achievement raises a lot of ethical issues that need to be carefully considered. In this direction, Arndt et al. (2022) stated that a balanced approach is needed to evaluate animal welfare by considering both internal and external factors that may affect animals during genetic interventions [76]. This ethical issue requires ongoing surveillance and assessment of animal health following intervention to ensure that welfare standards are upheld. Developing new biotechnology innovations for livestock breeds often involves complex intellectual property rights issues. As Chazhaev et al. (2023) state, patenting genetic materials could render smallholder farmers unable to obtain access to these resources and may lead to ethical issues surrounding ownership and control of genetic resources [77]. If the tools are not available for individuals who are actively controlling livestock populations, this could make conservation efforts less effective. Moreover, some worry that reliance on a narrow genetic base may compromise the adaptability of populations to environmental changes or diseases [78]. However, techniques such as SCNT can help regain key genetic traits.

On the other hand, there is continuous controversy about whether the embryos obtained via SCNT should receive the same ethical consideration as spontaneously created embryos. These issues concentrate around the ethical implications of permission and whether it is legal to use cloned organisms for research or as a source of organ donation [79,80]. Furthermore, studies demonstrate a high prevalence of malformations and fetal mortality in cloned animals, raising concerns regarding the legitimacy of such treatments considering the implications for animal well-being [81,82]. Furthermore, the low success rates inherent in SCNT (typically less than 5% in many species) accentuate these ethical problems, indicating that significant advances in procedures are required before broad deployment may be considered acceptable [83,84]. Similarly, gene editing technologies, particularly CRISPR-Cas9, raise a number of ethical concerns, primarily over potential germline changes. The ability to alter the germline raises worries about unexpected consequences that could be passed down to future generations, undermining their autonomy and the ethical precept of “do no harm” [85]. For example, in humans, the birth of gene-edited twins in China in 2018 sparked intense debate about the governance and societal implications of such technologies, prompting calls for restrictions on germline editing until comprehensive

ethical frameworks could be established [86,87]. The possibility for gene editing to worsen societal disparities is also worth investigating. If socioeconomic differences limit access to these strong technologies, they risk creating a two-tiered society that favors the genetically modified over the unaltered [88,89]. Several stakeholders, including humanitarian groups and bioethicists, argue that there is an urgent need for inclusive discourses that include varied viewpoints on justice, ethics, and social acceptability of genetic changes [90,91]. Stakeholders' viewpoints vary according to their interests. Scientists frequently emphasize the revolutionary power of these technologies in eradicating hereditary disorders and improving agricultural methods. However, bioethicists and members of the public routinely express concern about the overall ethical implications of fundamentally modifying life, calling for rigorous oversight and discussions on ethics [92]. Regulatory organizations are challenged to provide guidelines that reflect these intricacies. For example, although some countries have embraced gene editing as a frontier for innovation, others have stringent limitations on germline manipulations due to profound ethical or religious beliefs [93,94]. This variation can lead to "regulatory tourism," in which new technologies are researched and applied in jurisdictions with more liberal legislation, possibly weakening global ethical standards [86,95]. The regulatory landscape for SCNT and gene editing differs widely around the globe. In nations like the United States, regulatory frameworks are generally influenced by existing rules governing medical ethics and stem cell research, resulting in a complex web of legislation that can complicate the application of these technologies [81,96]. In contrast, nations like Germany and Italy have outright restrictions on germline genetic changes, reflecting deeply ingrained social attitudes about the sanctity of human life [90]. The regulatory reaction to advances in SCNT and gene editing must strike a balance between innovation, ethics, and public feelings. The formation of international rules, informed by a diverse range of stakeholder input, is crucial to create frameworks that manage new technologies ethically while maintaining public trust [92].

Another challenge is that many conservation programs rely heavily on government funding or external grants, which can be unpredictable. For example, Ouédraogo et al. (2021) stated that limited investment in livestock improvement and conservation programs in Nigeria leads to poor performance of native breeds [97]. Many conservation initiatives may not be able to achieve their aims if they do not have long-term support. Often, short-term initiatives that fail to yield long-term results are used as funding for conservation strategies. The same study pointed out that many breeding initiatives are supported by external funding and do not receive additional financing once the project period ends. This raises concern about their long-term viability [97]. This can create a loop of short-term benefits without the development of strong, long-lasting conservation methods.

Numerous countries lack comprehensive legislation to facilitate livestock breed conservation, resulting in inadequate financing and resources. Mapiye et al. (2019) emphasize that indigenous cattle breeds in Southern Africa are typically neglected because there are not any government programs in place to protect their value [98]. This leads to low productivity and a higher chance of extinction [99]. Conservation projects can struggle to gain traction without strong policy frameworks that put local breeds first. Moreover, farmers may not want to join conservation programs because the regulations on breeding and protecting livestock are complex. Current agri-environment payment programs, which have the potential to aid livestock conservation, are frequently hindered by bureaucratic challenges, complicating farmers' access to the funding and resources essential for carrying out conservation strategies [100].

As a future direction, incorporating artificial intelligence (AI) and genetics into cattle breed conservation, particularly in smallholder settings, could improve the efficacy of conservation efforts by refining decision-making processes, enhancing genetic management

efficiency, and optimizing breeding techniques. Using AI algorithms to analyze data in digital herdbooks can make it easier to keep track of animal genetics. AI can find genetic patterns and possible problems far faster than traditional approaches by keeping detailed records of breeding, health, and performance. For example, community-based breeding programs (CBBPs) may use AI to look at the health and production statistics of smallholder livestock. This would help farmers make smart choices about how to breed their animals [60]. Farmers can use machine learning to make predictive models for genetic outcomes based on past data. This can help them choose animals that are most likely to have the qualities they want. These models could bring together several types of data, such as genetic, phenotypic, and environmental aspects, to improve breeding techniques. AI could help improve artificial insemination methods that are specific to the area, which would increase the genetic variety and productivity of smallholder dairy cattle [101]. If smallholder farmers learn how to use AI technologies and control genetics, they will be more likely to help with efforts to protect animals. Farmers can better employ AI-enhanced tools for managing livestock if they learn more about genetics and technology. To make this knowledge transfer easier, research institutions and local communities need to work together. Working together can help set up local AI programs or mobile apps that help farmers choose the best genetics for their crops while taking into account the genetic diversity of the area [102]. Combining AI with blockchain technology could help keep heritage and breeding data safe in livestock management. This combination can help farmers and consumers trust each other by giving them records of livestock breeding histories and health data that cannot be changed. Farmers will be more likely to help with conservation initiatives if they can show the breeding history of their animals in clear records. Nonetheless, actual evidence advocating for the integration of blockchain in cattle management is still developing and may necessitate additional validation [52].

5. Conclusions

In conclusion, there have been significant developments in the field of livestock breed conservation in recent years. Traditional methods and new biotechnology advances are coming together more and more. In situ and ex situ conservation measures are still important for maintaining genetic variety, but they rarely function well on their own, especially when genetic erosion occurs faster because of climate change and industrial livestock systems. However, in order to effectively combine traditional methods and modern strategies and ensure the long-term conservation of livestock breeds, researchers, policymakers, and practitioners must work collaboratively. Collaborative relationships can help to exchange knowledge and engage local stakeholders in breed conservation decision-making. Furthermore, increasing knowledge of the value of local breeds and their contributions to biodiversity, food security, and ecosystem health is critical. Non-governmental groups or government agencies should launch campaigns to educate both producers and consumers on the advantages of preserving and using local breeds. This can also entail creating educational materials for schools and institutions that emphasize the cultural and ecological importance of traditional livestock systems. Policymakers should create frameworks that encourage the conservation of indigenous breeds through direct financial support or subsidies, while promoting sustainable practices in agricultural policies. Furthermore, regulations that make it easier to market products obtained from local breeds, such as organic labeling or geographic indications, can help traditional livestock management systems remain economically viable. Furthermore, developing methods to monitor breed demographics and genetic diversity might help guide targeted conservation measures.

Researchers should try to combine classic conservation methods with novel tools, including genetic selection, artificial insemination, and cryopreservation. Investing in

research on the genetic characterization and health management of indigenous breeds can help to improve breeding programs while maintaining traditional practices and beliefs. Cryopreservation of germplasm (e.g., semen, embryos) from endangered breeds should be emphasized in order to establish valuable genetic banking systems. These projects could provide protection against future extinction hazards while also allowing for regulated breeding tactics that incorporate both traditional and modern practices. Policymakers should incorporate livestock conservation into larger land-use planning frameworks, ensuring that agricultural practices are in line with biodiversity and conservation objectives. Sustainable land management approaches should be promoted, combining agricultural output with the need to protect native breeds and ecosystems. This could include agroecological agricultural techniques that preserve genetic variation while producing food in a sustainable manner.

In the end, protecting livestock biodiversity requires a balance between tradition and innovation. To make food systems strong and keep animal genetic resources adaptable in the face of global change, we need a strategy that is multidimensional, interdisciplinary, and inclusive, based on both cutting-edge science and culturally ingrained practices.

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Abbreviations

The following abbreviations are used in this manuscript:

NE	Effective Population Size
SNPs	Single Nucleotide Polymorphisms
IVF	In Vitro Fertilization
SCNT	Somatic Cell Nuclear Transfer
ARTs	Assisted Reproductive Technologies
AI	Artificial Intelligence
ICSI	Intra-Cytoplasmic Sperm Injection

References

1. Eusebi, P.G.; Martinez, A.; Cortes, O. Genomic Tools for Effective Conservation of Livestock Breed Diversity. *Diversity* **2019**, *12*, 8. [CrossRef]
2. Menger, A.K.; Hamm, U. Consumers' Knowledge and Perceptions of Endangered Livestock Breeds: How Wording Influences Conservation Efforts. *Ecol. Econ.* **2021**, *188*, 107117. [CrossRef]
3. Hemachand, N.S.; Bharath, V.S.; Phanindra, J.; Athota, H. Exploring Adaptive Genetic Traits in Domestic Farm Animals: A Comprehensive Review. *Act. Sci. Vet. Sci.* **2023**, *5*, 64–67. [CrossRef]
4. Khandoker, M.Y.; Ali, M.Y.; Akter, T.; Akhtar, M.M.; Kona, M.K.; Meki, N.J.; Sompa, M.R.; Meem, I.J. Population Distribution and Breeding Practices of Livestock in Different Districts of Bangladesh. *Asian Australas. J. Biosci. Biotechnol.* **2023**, *8*, 38–48. [CrossRef]

5. Malcom, A. Integrating Indigenous Knowledge into Livestock Policy Formulation. *IJLP* **2024**, *3*, 30–42. [CrossRef]
6. Tenzin, J.; Chankitisakul, V.; Boonkum, W. Current Status and Conservation Management of Farm Animal Genetic Resources in Bhutan. *Vet. Sci.* **2023**, *10*, 281. [CrossRef]
7. Aguilera-Alcalá, N.; Arrondo, E.; Pascual-Rico, R.; Morales-Reyes, Z.; Gil-Sánchez, J.M.; Donázar, J.A.; Moleón, M.; Sánchez-Zapata, J.A. The Value of Transhumance for Biodiversity Conservation: Vulture Foraging in Relation to Livestock Movements. *Ambio* **2022**, *51*, 1330–1342. [CrossRef]
8. Root-Bernstein, M.; Vargas, B.H.; Bondoux, A.; Guerrero-Gatica, M.; Zorondo-Rodríguez, F.; Huerta, M.; Valenzuela, R.; Bello, Á.V. Silvopastoralism, Local Ecological Knowledge and Woodland Trajectories in a Category V-Type Management Area. *Biodivers. Conserv.* **2022**, *31*, 543–564. [CrossRef]
9. Jablonski, K.E.; Merishi, J.; Dolrenry, S.; Hazzah, L. Ecological Doctors in Maasailand: Identifying Herding Best Practices to Improve Livestock Management and Reduce Carnivore Conflict. *Front. Sustain. Food Syst.* **2020**, *4*, 118. [CrossRef]
10. Osman, A.; Sbhatu, D.B.; Giday, M. Medicinal Plants Used to Manage Human and Livestock Ailments in Raya Kobo District of Amhara Regional State, Ethiopia. *Evid. Based Complement. Altern. Med.* **2020**, *2020*, 1329170. [CrossRef]
11. Swain, S.; Bhattacharya, S.; Chakrabarty, S. Ethnoveterinary Practice Followed by Santhal Tribes to Treat Foot and Mouth Diseases of Livestock in Ghatshila Block, Jharkhand, India. *JMHE* **2020**, *6*, 48–51. [CrossRef]
12. Rahman, I.U.; Ijaz, F.; Bussmann, R.W. Editorial: Ethnoveterinary Practices in Livestock: Animal Production, Healthcare, and Livelihood Development. *Front. Vet. Sci.* **2023**, *9*, 1086311. [CrossRef] [PubMed]
13. Azhar, B.; Tohiran, K.A.; Nobilly, F.; Zulkifli, R.; Syakir, M.I.; Ishak, Z.; Razi, N.; Oon, A.; Shahdan, A.; Maxwell, T.M.R. Time to Revisit Oil Palm-Livestock Integration in the Wake of United Nations Sustainable Development Goals (SDGs). *Front. Sustain. Food Syst.* **2021**, *5*, 640285. [CrossRef]
14. Musara, J.P.; Tibugari, H.; Moyo, B.; Mutizira, C. Crop-Livestock Integration Practices, Knowledge, and Attitudes among Smallholder Farmers: Hedging against Climate Change-Induced Shocks in Semi-Arid Zimbabwe. *Open Life Sci.* **2021**, *16*, 1330–1340. [CrossRef]
15. Fedorca, A.; Mergeay, J.; Akinyele, A.O.; Albayrak, T.; Biebach, I.; Brambilla, A.; Burger, P.A.; Buzan, E.; Curik, I.; Gargiulo, R.; et al. Dealing with the Complexity of Effective Population Size in Conservation Practice. *Evol. Appl.* **2024**, *17*, e70031. [CrossRef]
16. Ladyka, V.; Skliarenko, Y.; Kovtun, P.S.; Tatiana, D.; Viktoriy, V.; Malikova, A. Evaluation of Stud Bulls by Beta-Casein Genotype in the Context of Conservation of Local Cattle Breeds in Ukraine. *Sci. Pap. Ser. D. Anim. Sci.* **2023**, *LXVI*, 42–47.
17. Surlea, C.; Mateescu, C.; Dinita, G.; Cringanu, I.; Grosu, H.; Nicolae, C.G. Research on Characters Conservation in Mountain Ecotype Queen Bees. *Sci. Pap. Ser. D. Anim. Sci.* **2024**, *LXVII*, 307.
18. Davidescu, M.; Madescu, B.; Ciorpac, M.; Dascalu, L.; Bugeac, T.; Andrei, M.; Porosnicu, I.; Steofil, C. Genetic Diversity of Pinzgau Cattle Breed: A Systematic Review. *Sci. Pap. Ser. D. Anim. Sci.* **2024**, *LXIV*, 2.
19. Davidescu, M.-A.; Simeanu, D.; Simeanu, C.; Panzaru, C.; Usturoi, A.; Creanga, S. Analysis of Blood Biochemical Profile of Endangered Romanian Grey Cows According to Age. *Sci. Pap. Ser. D. Anim. Sci.* **2024**, *LXVII*, 2.
20. Mureithi, S.; Verdoodt, A.; Njoka, J.T.; Olesarioyo, J.S.; Van Ranst, E. Community-Based Conservation: An Emerging Land Use at the Livestock-Wildlife Interface in Northern Kenya. In *Wildlife Management—Failures, Successes and Prospects*; Kideghesho, J.R., Rija, A.A., Eds.; IntechOpen: London, UK, 2019; ISBN 978-1-78985-291-2.
21. Velado-Alonso, E.; Morales-Castilla, I.; Rebollo, S.; Gómez-Sal, A. Relationships between the Distribution of Wildlife and Livestock Diversity. *Divers. Distrib.* **2020**, *26*, 1264–1275. [CrossRef]
22. Gladkikh, T.M.; Collazo, J.A.; Torres-Abreu, A.; Reyes, A.M.; Molina, M. Factors That Influence Participation of Puerto Rican Coffee Farmers in Conservation Programs. *Conserv. Sci. Pr.* **2020**, *2*, e172. [CrossRef]
23. Medina, G.; Isley, C.; Arbuckle, J. Iowa Farm Environmental Leaders' Perspectives on the U.S. Farm Bill Conservation Programs. *Front. Sustain. Food Syst.* **2020**, *4*, 497943. [CrossRef]
24. Roche, B.; Farruggia, A.; Pousin, M.; Riga, P.; Chataigner, C.; Boutifard, V.; Prieur, M.; Roux, P.; Cooke, A.S.; Rivero, M.J. The Maraichine Cattle Breed Supports Breeders and Researchers in the Atlantic Coastal Marshlands. *Ruminants* **2022**, *2*, 173–187. [CrossRef]
25. Sponenberg, D.P.; Martin, A.; Couch, C.; Beranger, J. Conservation Strategies for Local Breed Biodiversity. *Diversity* **2019**, *11*, 177. [CrossRef]
26. Yadav, N.; Mukherjee, A.; Pannu, U.; Gujar, G. Approach and Prospects of Landscape Genetics in Livestock: A Review. *ELSR* **2023**, *9*, 33–39. [CrossRef]
27. Trzcińska, M.; Samiec, M. *Ex. Situ* Conservation and Genetic Rescue of Endangered Polish Cattle and Pig Breeds with the Aid of Modern Reproductive Biotechnology—A Review. *Ann. Anim. Sci.* **2021**, *21*, 1193–1207. [CrossRef]
28. Tomka, J.; Huba, J.; Pavlík, I. State of Conservation of Animal Genetic Resources in Slovakia. *GenResJ* **2022**, *3*, 49–63. [CrossRef]
29. Sun, Y.; Li, Y.; Zong, Y.; Mehaisen, G.M.K.; Chen, J. Poultry Genetic Heritage Cryopreservation and Reconstruction: Advancement and Future Challenges. *J. Anim. Sci. Biotechnol.* **2022**, *13*, 115. [CrossRef] [PubMed]

30. De Oliveira Silva, R.; Cortes Gardyn, O.; Hiemstra, S.-J.; Oliveira Marques, J.G.; Tixier-Boichard, M.; Moran, D. Rationalizing *Ex. Situ* Collection of Reproductive Materials for Endangered Livestock Breed Conservation. *Ecol. Econ.* **2021**, *181*, 106916. [CrossRef]
31. Farhadinia, M.S.; Johnson, P.J.; Zimmermann, A.; McGowan, P.J.K.; Meijaard, E.; Stanley-Price, M.; Macdonald, D.W. Ex Situ Management as Insurance against Extinction of Mammalian Megafauna in an Uncertain World. *Conserv. Biol.* **2020**, *34*, 988–996. [CrossRef]
32. Yang, H.; Huo, Y.; Yee, J.C.; Rikard, S.; Walton, W.C.; Saillant, E. Sperm Repository for a Breeding Program of the Eastern Oyster Crassostrea Virginica: Sample Collection, Processing, Cryopreservation, and Data Management Plan. *Animals* **2021**, *11*, 2836. [CrossRef] [PubMed]
33. Huang, Z.; Gao, L.; Hou, Y.; Zhu, S.; Fu, X. Cryopreservation of Farm Animal Gametes and Embryos: Recent Updates and Progress. *Front. Agr. Sci. Eng.* **2019**, *6*, 42. [CrossRef]
34. Elango, K.; Kumaresan, A.; Ashokan, M.; Karuthadurai, T.; Nag, P.; Bhaskar, M.; Prasad, B.A.; Jeyakumar, S.; Manimaran, A.; Bhat, V.; et al. Dynamics of Mitochondrial Membrane Potential and DNA Damage during Cryopreservation of Cattle and Buffalo Bull Spermatozoa. *Indian. J. Anim. Sci.* **2021**, *91*, 9–14. [CrossRef]
35. Dhali, A.; Kolte, A.P.; Mishra, A.; Roy, S.C.; Bhatta, R. Cryopreservation of Oocytes and Embryos: Current Status and Opportunities. In *Infertility, Assisted Reproductive Technologies and Hormone Assays*; Sultan Sheriff, D., Ed.; IntechOpen: London, UK, 2019. [CrossRef]
36. Nikitkina, E.V.; Dementieva, N.V.; Shcherbakov, Y.S.; Atroshchenko, M.M.; Kudinov, A.A.; Samoylov, O.I.; Pozovnikova, M.V.; Dysin, A.P.; Krutikova, A.A.; Musidray, A.A.; et al. Genome-Wide Association Study for Frozen-Thawed Sperm Motility in Stallions across Various Horse Breeds. *Anim. Biosci.* **2022**, *35*, 1827–1838. [CrossRef] [PubMed]
37. Zhu, Z.; Li, R.; Fan, X.; Lv, Y.; Zheng, Y.; Hoque, S.A.M.; Wu, D.; Zeng, W. Resveratrol Improves Boar Sperm Quality via 5′ AMP-Activated Protein Kinase Activation during Cryopreservation. *Oxidative Med. Cell. Longev.* **2019**, *2019*, 5921503. [CrossRef]
38. Ebenezer Samuel King, J.P.; Sinha, M.K.; Kumaresan, A.; Nag, P.; Das Gupta, M.; Arul Prakash, M.; Talluri, T.R.; Datta, T.K. Cryopreservation Process Alters the Expression of Genes Involved in Pathways Associated with the Fertility of Bull Spermatozoa. *Front. Genet.* **2022**, *13*, 1025004. [CrossRef]
39. Pimprasert, M.; Kheawkanha, T.; Boonkum, W.; Chankitisakul, V. Influence of Semen Collection Frequency and Seasonal Variations on Fresh and Frozen Semen Quality in Thai Native Roosters. *Animals* **2023**, *13*, 573. [CrossRef]
40. Tăpăloagă, P.-R.; Gheorghe-Irimia, R.A.; Tăpăloagă, T. Genomic Precision in Animal Reproduction: A Pathway to Enhanced Breeding Programs. *Rev. Rom. Med. Vet.* **2023**, *33*, 79–84.
41. Rather, H.A.; Kumaresan, A.; Nag, P.; Kumar, V.; Nayak, S.; Batra, V.; Ganaie, B.A.; Baithalu, R.K.; Mohanty, T.K.; Datta, T.K. Spermatozoa Produced during Winter Are Superior in Terms of Phenotypic Characteristics and Oviduct Explants Binding Ability in the Water Buffalo (*Bubalus bubalis*). *Reprod. Domest. Anim.* **2020**, *55*, 1629–1637. [CrossRef]
42. Trzcińska, M.; Samiec, M.; Duda, M. Creating Ex Situ Protected Bioreservoirs as a Powerful Strategy for the Reproductive Biotechnology-Mediated Rescue of Threatened Polish Livestock Breeds. *Agriculture* **2023**, *13*, 1426. [CrossRef]
43. Delgado Bermejo, J.V.; Martínez Martínez, M.A.; Rodríguez Galván, G.; Stemmer, A.; Navas González, F.J.; Camacho Vallejo, M.E. Organization and Management of Conservation Programs and Research in Domestic Animal Genetic Resources. *Diversity* **2019**, *11*, 235. [CrossRef]
44. Li, W.; Gao, C.; Cai, Z.; Yan, S.; Lei, Y.; Wei, M.; Sun, G.; Tian, Y.; Wang, K.; Kang, X. Assessing the Conservation Impact of Chinese Indigenous Chicken Populations between Ex-Situ and In-Situ Using Genome-Wide SNPs. *J. Integr. Agric.* **2024**, *23*, 975–987. [CrossRef]
45. Zhang, M.; Liu, Y.; Wang, S.; Zhang, H.; Sun, M.; Wang, J.; Wu, K. Conservation of Genomic Diversity and Breed-Specific Characteristics of Domestic Chickens in China. *Genet. Sel. Evol.* **2020**, *22*, 92. [CrossRef]
46. Arya, A.; Sharma, P.; Trivedi, M.M.; Modi, R.J.; Patel, Y.G. A Look at Genomic Selection Techniques for Climate Change Adaptation and Production in Livestock. *JSRR* **2024**, *30*, 427–436. [CrossRef]
47. Biscarini, F.; Mastrangelo, S.; Catillo, G.; Senczuk, G.; Ciampolini, R. Insights into Genetic Diversity, Runs of Homozygosity and Heterozygosity-Rich Regions in Maremmana Semi-Feral Cattle Using Pedigree and Genomic Data. *Animals* **2020**, *10*, 2285. [CrossRef] [PubMed]
48. Szmatoła, T.; Gurgul, A.; Jasielczuk, I.; Ząbek, T.; Ropka-Molik, K.; Litwińczuk, Z.; Bugno-Poniewierska, M. A Comprehensive Analysis of Runs of Homozygosity of Eleven Cattle Breeds Representing Different Production Types. *Animals* **2019**, *9*, 1024. [CrossRef] [PubMed]
49. Selokar, N.L.; Sharma, P.; Saini, M.; Sheoran, S.; Rajendran, R.; Kumar, D.; Sharma, R.K.; Motiani, R.K.; Kumar, P.; Jerome, A.; et al. Successful Cloning of a Superior Buffalo Bull. *Sci. Rep.* **2019**, *9*, 11366. [CrossRef] [PubMed]
50. Fatira, E.; Havelka, M.; Labbé, C.; Depincé, A.; Pšenička, M.; Saito, T. A Newly Developed Cloning Technique in Sturgeons; an Important Step towards Recovering Endangered Species. *Sci. Rep.* **2019**, *9*, 10453. [CrossRef]
51. Carolino, N.; Vitorino, A.; Carolino, I.; Pais, J.; Henriques, N.; Silveira, M.; Vicente, A. Genetic Diversity in the Portuguese Mertolenga Cattle Breed Assessed by Pedigree Analysis. *Animals* **2020**, *10*, 1990. [CrossRef]

52. Markov, N.; Stoycheva, S.; Hristov, M.; Mondeshka, L. Digital Management of Technological Processes in Cattle Farms: A Review. *J. Cent. Eur. Agric.* **2022**, *23*, 486–495. [CrossRef]
53. Yadav, A.; Shivani, S.; Manda, V.K.; Sangwan, V.; Demkiv, A. Blockchain Technology for Ecological and Environmental Applications. *EQ* **2024**, *35*, 91–102. [CrossRef]
54. Kamble, S.S.; Gunasekaran, A.; Sharma, R. Modeling the Blockchain Enabled Traceability in Agriculture Supply Chain. *Int. J. Inf. Manag.* **2020**, *52*, 101967. [CrossRef]
55. Gao, J.; Sun, L.; Zhang, S.; Xu, J.; He, M.; Zhang, D.; Wu, C.; Dai, J. Screening Discriminating SNPs for Chinese Indigenous Pig Breeds Identification Using a Random Forests Algorithm. *Genes* **2022**, *13*, 2207. [CrossRef] [PubMed]
56. Xu, B.; Wang, W.; Falzon, G.; Kwan, P.; Guo, L.; Sun, Z.; Li, C. Livestock Classification and Counting in Quadcopter Aerial Images Using Mask R-CNN. *Int. J. Remote Sens.* **2020**, *41*, 8121–8142. [CrossRef]
57. Lee, W.; Ham, Y.; Ban, T.-W.; Jo, O. Analysis of Growth Performance in Swine Based on Machine Learning. *IEEE Access* **2019**, *7*, 161716–161724. [CrossRef]
58. Seo, D.; Cho, S.; Manjula, P.; Choi, N.; Kim, Y.-K.; Koh, Y.J.; Lee, S.H.; Kim, H.-Y.; Lee, J.H. Identification of Target Chicken Populations by Machine Learning Models Using the Minimum Number of SNPs. *Animals* **2021**, *11*, 241. [CrossRef]
59. Darmawan, H.; Chang, H.-L.; Wu, H.-H. A Community-Based Breeding Program as a Genetic Resource Management Strategy of Indonesian Ongole Cattle. *Sustainability* **2023**, *15*, 6013. [CrossRef]
60. Wurzinger, M.; Gutiérrez, G.A.; Sölkner, J.; Probst, L. Community-Based Livestock Breeding: Coordinated Action or Relational Process? *Front. Vet. Sci.* **2021**, *8*, 613505. [CrossRef]
61. Juvančič, L.; Slabe-Erker, R.; Ogorevc, M.; Drucker, A.G.; Erjavec, E.; Bojkovski, D. Payments for Conservation of Animal Genetic Resources in Agriculture: One Size Fits All? *Animals* **2021**, *11*, 846. [CrossRef]
62. Gicquel, E.; Boettcher, P.; Besbes, B.; Furre, S.; Fernández, J.; Danchin-Burge, C.; Berger, B.; Baumung, R.; Feijóo, J.R.J.; Leroy, G. Impact of Conservation Measures on Demography and Genetic Variability of Livestock Breeds. *Animal* **2020**, *14*, 670–680. [CrossRef]
63. Mongke, T.; Budsuren, U.; Tiemuqier, A.; Bozlak, E.; Wallner, B.; Dulamsuren, S.; Daidiikhuu, D.; Amgalan, S.; An, T.; Mongkejargal, B.; et al. Genomic Conservation of Mongolian Horses Promoted by Preservation of the Intangible Cultural Heritage of Naadam in Mongolia. *Conserv. Lett.* **2024**, *17*, e13019. [CrossRef]
64. Zhao, Q.; Liu, H.; Qadri, Q.R.; Wang, Q.; Pan, Y.; Su, G. Long-Term Impact of Conventional and Optimal Contribution Conservation Methods on Genetic Diversity and Genetic Gain in Chinese Indigenous Pig Breeds. *Heredity* **2021**, *127*, 546–553. [CrossRef] [PubMed]
65. Cao, J.; Baumung, R.; Boettcher, P.; Scherf, B.; Besbes, B.; Leroy, G. Monitoring and Progress in the Implementation of the Global Plan of Action on Animal Genetic Resources. *Sustainability* **2021**, *13*, 775. [CrossRef]
66. Abu, E. Review on Population Status and Conservation Activity of Indigenous Cattle Breeds of Ethiopia. *JBAH* **2021**, *4*, 32–39. [CrossRef]
67. Roessler, R. Selection Decisions and Trait Preferences for Local and Imported Cattle and Sheep Breeds in Peri-/Urban Livestock Production Systems in Ouagadougou, Burkina Faso. *Animals* **2019**, *9*, 207. [CrossRef]
68. Houessou, S.O.; Dossa, L.H.; Diogo, R.V.C.; Ahozonlin, M.C.; Dahouda, M.; Schlecht, E. Confronting Pastoralists' Knowledge of Cattle Breeds Raised in the Extensive Production Systems of Benin with Multivariate Analyses of Morphological Traits. *PLoS ONE* **2019**, *14*, e0222756. [CrossRef]
69. Kaumbata, W.; Nakimbugwe, H.; Nandolo, W.; Banda, L.J.; Mészáros, G.; Gondwe, T.; Woodward-Greene, M.J.; Rosen, B.D.; Van Tassell, C.P.; Sölkner, J.; et al. Experiences from the Implementation of Community-Based Goat Breeding Programs in Malawi and Uganda: A Potential Approach for Conservation and Improvement of Indigenous Small Ruminants in Smallholder Farms. *Sustainability* **2021**, *13*, 1494. [CrossRef]
70. Okpeku, M.; Ogah, D.M.; Adeleke, M.A. A Review of Challenges to Genetic Improvement of Indigenous Livestock for Improved Food Production in Nigeria. *AJFAND* **2019**, *19*, 13959–13978. [CrossRef]
71. Giovannini, S.; Chessari, G.; Riggio, S.; Marletta, D.; Sardina, M.T.; Mastrangelo, S.; Sarti, F.M. Insight into the Current Genomic Diversity, Conservation Status and Population Structure of Tunisian Barbarine Sheep Breed. *Front. Genet.* **2024**, *15*, 1379086. [CrossRef]
72. Velado-Alonso, E.; Gómez-Sal, A.; Bernués, A.; Martín-Collado, D. Disentangling the Multidimensional Relationship between Livestock Breeds and Ecosystem Services. *Animals* **2021**, *11*, 2548. [CrossRef]
73. Santillo, A.; Della Malva, A.; Albenzio, M. Preserving Biodiversity of Sheep and Goat Farming in the Apulia Region. *Animals* **2025**, *15*, 1610. [CrossRef]
74. Lauvie, A.; Alexandre, G.; Angeon, V.; Couix, N.; Fontaine, O.; Gaillard, C.; Meuret, M.; Mougenot, C.; Moulin, C.-H.; Naves, M.; et al. Is the Ecosystem Services Concept Relevant to Capture the Multiple Benefits from Farming Systems Using Livestock Biodiversity? A Framework Proposal. *GenResJ* **2023**, *4*, 15–28. [CrossRef]

75. Leroy, G.; Boettcher, P.; Besbes, B.; Peña, C.R.; Jaffrezic, F.; Baumung, R. Food Securers or Invasive Aliens? Trends and Consequences of Non-Native Livestock Introgression in Developing Countries. *Glob. Food Secur.* **2020**, *26*, 100420. [CrossRef]
76. Arndt, S.S.; Goerlich, V.C.; Van Der Staay, F.J. A Dynamic Concept of Animal Welfare: The Role of Appetitive and Adverse Internal and External Factors and the Animal's Ability to Adapt to Them. *Front. Anim. Sci.* **2022**, *3*, 908513. [CrossRef]
77. Chazhaev, M. Economic Potential of Biotechnologies: Challenges and Windows of Opportunity. *BIO Web Conf.* **2023**, *76*, 10002. [CrossRef]
78. Al Hakim, R.R.; Saputro, T.A. Development of Somatic Cell Nuclear Transfer Biotechnology for Cloning of Animals: A Mini-Review. *J. Biol. Instr.* **2021**, *1*, 20–27. [CrossRef]
79. Gouveia, C.; Huyser, C.; Egli, D.; Pepper, M.S. Lessons Learned from Somatic Cell Nuclear Transfer. *Int. J. Mol. Sci.* **2020**, *21*, 2314. [CrossRef] [PubMed]
80. Alberio, R.; Wolf, E. Nuclear Transfer and the Development of Genetically Modified/Gene Edited Livestock. *Reproduction* **2021**, *162*, F59–F68. [CrossRef]
81. Wang, X.; Liu, D.; Liu, J. Formality or Reality: Student Teachers' Experiences of Ethical Dilemmas and Emotions During the Practicum. *Front. Psychol.* **2022**, *13*, 870069. [CrossRef]
82. Liu, Z.; Cai, Y.; Liao, Z.; Xu, Y.; Wang, Y.; Wang, Z.; Jiang, X.; Li, Y.; Lu, Y.; Nie, Y.; et al. Cloning of a Gene-Edited Macaque Monkey by Somatic Cell Nuclear Transfer. *Natl. Sci. Rev.* **2019**, *6*, 101–108. [CrossRef]
83. Klinger, B.; Schnieke, A. Twenty-Five Years after Dolly—How Far Have We Come? *Reproduction* **2021**, *162*, F1–F10. [CrossRef]
84. Wang, L.-Y.; Li, Z.-K.; Wang, L.-B.; Liu, C.; Sun, X.-H.; Feng, G.-H.; Wang, J.-Q.; Li, Y.-F.; Qiao, L.-Y.; Nie, H.; et al. Overcoming Intrinsic H3K27me3 Imprinting Barriers Improves Post-Implantation Development after Somatic Cell Nuclear Transfer. *Cell Stem Cell* **2020**, *27*, 315–325.e5. [CrossRef]
85. Yeung, T.; Bhatia, S.K. Embryo Editing Technology and Its Effect on Conceptions of Motherhood. In Proceedings of the 8th World Congress on New Technologies, ICBB 005, Prague, Czech Republic, 3–5 August 2022; pp. 1–8. [CrossRef]
86. Peng, Y.; Lv, J.; Ding, L.; Gong, X.; Zhou, Q. Responsible Governance of Human Germline Genome Editing in China. *Biol. Reprod.* **2022**, *107*, 261–268. [CrossRef] [PubMed]
87. Lei, R.; Qiu, R. Ethical and Regulatory Issues in Human Gene Editing: Chinese Perspective. *Biotech. Appl. Biochem.* **2020**, *67*, 880–891. [CrossRef] [PubMed]
88. Astarăstoae, V.; Ioan, B.G.; Rogozea, L.M.; Hanganu, B. Advances in Genetic Editing of the Human Embryo. *Am. J. Ther.* **2023**, *30*, e126–e133. [CrossRef] [PubMed]
89. Almeida, M.; Ranisch, R. Beyond Safety: Mapping the Ethical Debate on Heritable Genome Editing Interventions. *Humanit. Soc. Sci. Commun.* **2022**, *9*, 139. [CrossRef]
90. Abuhammad, S.; Khabour, O.F.; Alzoubi, K.H. Researchers Views about Perceived Harms and Benefits of Gene Editing: A Study from the MENA Region. *Heliyon* **2021**, *7*, e06860. [CrossRef]
91. Zhang, D.; Hussain, A.; Manghwar, H.; Xie, K.; Xie, S.; Zhao, S.; Larkin, R.M.; Qing, P.; Jin, S.; Ding, F. Genome Editing with the CRISPR-Cas System: An Art, Ethics and Global Regulatory Perspective. *Plant Biotechnol. J.* **2020**, *18*, 1651–1669. [CrossRef]
92. Ammari, A.A.; ALGhadi, M.G.; Amran, R.A.; Al Malahi, N.M.; Alhimaidi, A.R. Interspecific Nuclear Transfer Blastocysts Reconstructed from Arabian Oryx Somatic Cells and Domestic Cow Ooplasm. *Vet. Sci.* **2022**, *10*, 17. [CrossRef]
93. Cwik, B. Intergenerational Monitoring in Clinical Trials of Germline Gene Editing. *J. Med. Ethics* **2020**, *46*, 183–187. [CrossRef]
94. Konno, S.; Wakayama, S.; Ito, D.; Kazama, K.; Hirose, N.; Ooga, M.; Wakayama, T. Removal of Remodeling/Reprogramming Factors from Oocytes and the Impact on the Full-Term Development of Cloned Embryos. *Development* **2020**, *147*, dev190777. [CrossRef] [PubMed]
95. Diana, I.M. Ethics in Gene Editing. *Nat. Sci. Eng. Technol. J.* **2021**, *1*, 12–16. [CrossRef]
96. Sun, J.; Zheng, W.; Liu, W.; Kou, X.; Zhao, Y.; Liang, Z.; Wang, L.; Zhang, Z.; Xiao, J.; Gao, R.; et al. Differential Transcriptomes and Methylomes of Trophoblast Stem Cells From Naturally-Fertilized and Somatic Cell Nuclear-Transferred Embryos. *Front. Cell Dev. Biol.* **2021**, *9*, 664178. [CrossRef] [PubMed]
97. Ouédraogo, D.; Soudré, A.; Yougbaré, B.; Ouédraogo-Koné, S.; Zoma-Traoré, B.; Khayatzadeh, N.; Traoré, A.; Sanou, M.; Mészáros, G.; Burger, P.A.; et al. Genetic Improvement of Local Cattle Breeds in West Africa: A Review of Breeding Programs. *Sustainability* **2021**, *13*, 2125. [CrossRef]
98. Mapiye, C.; Chikwanha, O.C.; Chimonyo, M.; Dzama, K. Strategies for Sustainable Use of Indigenous Cattle Genetic Resources in Southern Africa. *Diversity* **2019**, *11*, 214. [CrossRef]
99. Smith, M.; Dawson, J.C. *Participatory Plant Breeding Programs to Optimize Use of Crop Genetic Resources*; Burleigh Dodds Science Publishing: Cambridge, UK, 2021; pp. 251–270.
100. Puneeth, G.M.; Deepak, D.A.; Sneha, G.R.; Gowthami, R.; Chander, S.; Bhatt, K.C.; Vasudeva, R.; Archak, S. A Review of Landraces' On-Farm Conservation, Practices and Management: An Indian Perspective. *J. Sci. Res. Rep.* **2024**, *30*, 910–923. [CrossRef]

101. Korir, L.; Manning, L.; Moore, H.L.; Lindahl, J.F.; Gemechu, G.; Mihret, A.; Berg, S.; Wood, J.L.N.; Nyokabi, N.S. Adoption of Dairy Technologies in Smallholder Dairy Farms in Ethiopia. *Front. Sustain. Food Syst.* **2023**, *7*, 1070349. [CrossRef]
102. Mutenje, M.; Chipfupa, U.; Mupangwa, W.; Nyagumbo, I.; Manyawu, G.; Chakoma, I.; Gwiriri, L. Understanding Breeding Preferences among Small-Scale Cattle Producers: Implications for Livestock Improvement Programmes. *Animal* **2020**, *14*, 1757–1767. [CrossRef]

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