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# Selection and Breeding of Livestock for Climate Resilience: A Review

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## Abstract

Increasing climatic variability poses a major threat to sustainable livestock production through rising temperatures, heat waves, drought, water scarcity, extreme weather events, and changing disease and parasite patterns. These stresses adversely affect animal health, growth, production, reproduction, feed availability, and survival. Climate-resilient livestock can maintain productivity, health, reproductive performance, and survival under environmental stress through traits such as heat and drought tolerance, disease and parasite resistance, feed efficiency, and water-use efficiency. Indigenous breeds are valuable genetic resources because of their adaptation to harsh environments and their ability to utilize poor-quality feed and withstand climatic and disease challenges. Genetic selection provides a sustainable approach to climate adaptation, with conventional methods such as phenotypic, pedigree, and progeny selection complemented by marker-assisted selection, genomic selection, GWAS, and precision livestock breeding. Candidate genes such as SLICK, HSP70, HSP90, and HSF1 contribute to thermotolerance and heat-stress responses. However, breeding for climate resilience is challenged by low heritability, difficulty in phenotyping, genotype × environment interactions, limited genomic information, high technological costs, loss of genetic diversity, and inadequate infrastructure. Integrating indigenous genetic resources with conventional and advanced genomic approaches can accelerate the development of climate-smart livestock capable of maintaining productivity, health, welfare, and resource-use efficiency under changing climatic conditions, thereby improving sustainability, profitability, and food security.

**Keywords:** Climate-resilient livestock; Heat stress; Genetic selection; Indigenous breeds; Genomic selection; Climate-smart breeding.

## Introduction

Climate change is one of the major challenges affecting agricultural and livestock production. It is characterized by rising temperatures, erratic rainfall, droughts, water scarcity, and increased frequency of extreme weather events, mainly due to increasing greenhouse gas emissions. Livestock are highly sensitive to these changes. Heat stress, feed and water shortages, and increased disease and parasite pressure can reduce feed intake, growth, milk and meat production, reproductive efficiency, immunity, and survival. Climate change also affects the availability and quality of fodder and increases production costs, threatening the profitability and sustainability of livestock farming (IPCC, 2023; FAO, 2023; Rojas-Downing et al., 2017). Climate-resilient livestock are animals that can withstand, adapt to, and recover from environmental stresses while maintaining acceptable productivity, health, and reproductive performance. Important resilience traits include heat tolerance, drought tolerance, disease and parasite resistance, feed efficiency, and water-use efficiency. Indigenous breeds are particularly valuable because they have evolved under harsh local conditions and often possess superior adaptive traits such as efficient thermoregulation, better utilization of poor-quality feed, disease resistance, and lower water requirements (Sejian et al., 2022; Mrode et al., 2024).

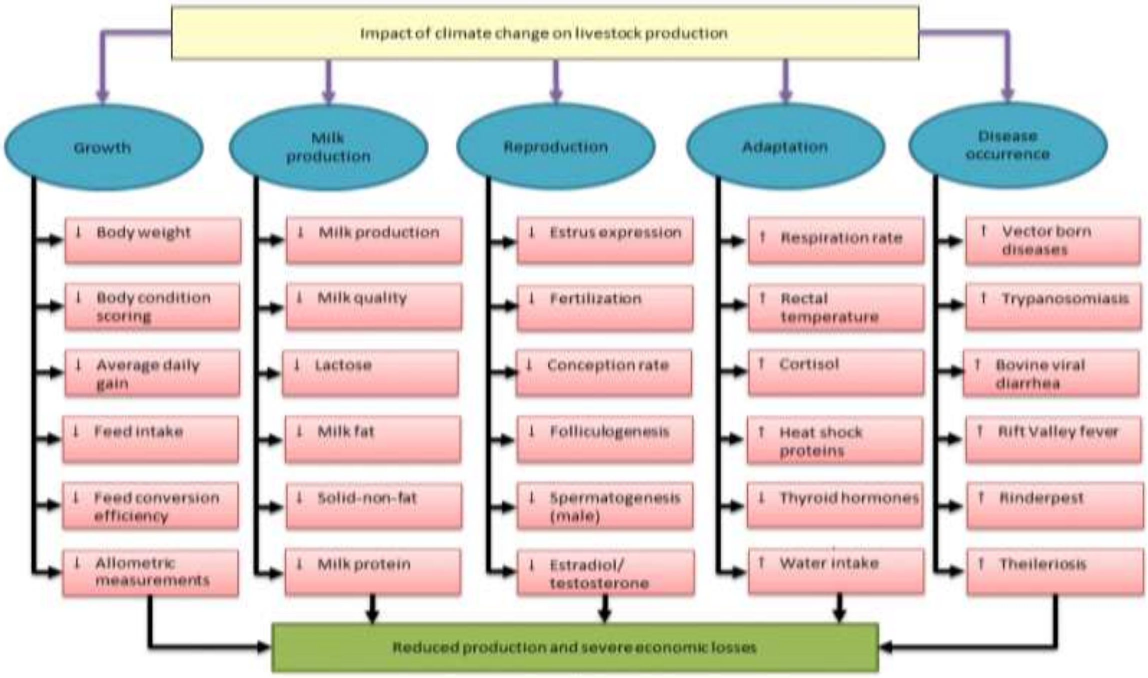
Genetic selection and breeding provide a sustainable long-term approach to climate adaptation because genetic improvement is cumulative and can be passed to future generations. Conventional selection can be combined with marker-assisted selection (MAS), genomic selection (GS), and genome-wide association studies (GWAS) to identify genes and genomic regions associated with climate-resilience traits. Important candidate genes include SLICK, HSP70, HSP90, HSF1, BoLA, NRAMP1, LEP, and IGF-1. Incorporating these traits into breeding objectives can improve animal welfare, productivity, reproductive efficiency, resource-use efficiency, profitability, and food security under changing climatic conditions (FAO, 2023; Mrode et al., 2024).

## Climate Change and Livestock Production

Climate change is increasingly affecting livestock production worldwide by altering temperature, humidity, rainfall, and the frequency of extreme weather events, thereby impacting animal health, productivity, reproduction, feed and water availability, and disease dynamics. Rising temperatures cause heat stress, leading to reduced feed intake, growth, milk production, reproductive performance, metabolic function, and immunity, particularly in high-producing dairy cattle (IPCC, 2023; Thornton et al., 2024). Increasing heat waves further intensify thermal stress, causing elevated respiration and body temperature, reduced feed intake, reproductive failure, disease susceptibility, and mortality, resulting in substantial economic losses (Mrode et al., 2024). Drought and water scarcity reduce pasture productivity and forage quality, increase feed costs, and impair hydration, thermoregulation, metabolism, and overall animal performance, particularly affecting smallholder farmers in arid and semi-arid regions (FAO, 2023). Extreme weather events such as floods, cyclones, storms, and wildfires can cause livestock mortality, injuries, displacement, infrastructure damage, disease spread, and disruption of feed supply chains (IPCC, 2023). Furthermore, changes in temperature and rainfall patterns can alter the distribution and transmission of diseases, parasites, and vectors such as ticks, mosquitoes, and flies, increasing morbidity, mortality, veterinary costs, and production losses. Thus, climate change poses significant challenges to livestock health, productivity, welfare, and the sustainability of livestock production systems (Rojas-Downing et al., 2017; Thornton et al., 2024).

### Impact of Climate Change on Livestock




### Climate Resilience Traits in Livestock

Climate resilience in livestock refers to the ability of animals to maintain health, productivity, reproductive efficiency, and survival under adverse climatic conditions such as heat stress, drought, feed scarcity, water shortages, and increased disease challenges. Climate-resilient livestock possess a combination of **adaptive traits** and **productive traits** that enable them to cope with environmental stresses while sustaining economic performance. These traits are increasingly being incorporated into breeding programs to develop livestock populations capable of thriving under future climate scenarios.

**A. Adaptive Traits -** Adaptive traits are characteristics that enhance an animal's ability to survive and function under environmental stress conditions.

### 1. Heat Tolerance

Heat tolerance is the ability of livestock to maintain normal physiological functions, health, production, and reproduction under high temperature and humidity. Heat-tolerant animals regulate body temperature more efficiently through sweating, respiration, and better heat dissipation, and generally maintain lower rectal temperature, better feed intake, growth, milk production, and fertility during heat stress. Important genetic factors include HSP70 and HSP90, which protect cells from heat-induced damage, and the SLICK gene, which produces a short, sleek hair coat that facilitates heat loss. Therefore, heat tolerance is an important breeding objective for climate-resilient livestock production, helping reduce production losses and improve animal welfare under rising temperatures (Brito et al., 2024; Nguyen et al., 2023; Sejian et al., 2022).

### 2. Drought Tolerance

Drought tolerance is the ability of livestock to survive and maintain acceptable productivity during prolonged water scarcity, poor pasture availability, and feed shortages. Drought-tolerant animals conserve water, efficiently utilize low-quality and fibrous feeds, reduce maintenance energy requirements, and can mobilize body reserves during periods of nutritional stress. Indigenous breeds of cattle, sheep, and goats are particularly valuable because they have evolved these adaptive traits under harsh environments. Thus, drought tolerance is an important climate-resilience trait that improves animal survival, stabilizes productivity, reduces dependence on external feed and water, and supports sustainable livestock production in water-scarce regions (FAO, 2023; Sejian et al., 2022; Mrode et al., 2024).

**3. Disease Resistance**

Disease resistance is the ability of livestock to prevent infection, control pathogen multiplication, and reduce disease severity through genetic and immune mechanisms. It is an important climate-resilience trait because climate change can increase the prevalence and spread of pathogens, parasites, and disease vectors. Disease-resistant animals show lower morbidity and mortality, faster recovery, reduced pathogen load, and better productivity, while requiring fewer veterinary treatments. Examples include mastitis resistance in dairy cattle, gastrointestinal parasite resistance in sheep and goats, and tick-borne disease resistance in indigenous cattle. Therefore, breeding for disease resistance improves animal health and welfare, reduces treatment costs and antibiotic use, and supports sustainable and climate-resilient livestock production (Bishop & Woolliams, 2023; FAO, 2023; Mrode et al., 2024).

**4. Parasite Resistance**

Parasite resistance is the ability of livestock to prevent or control internal and external parasites through genetic, physiological, and immune mechanisms. It is an important climate-resilience trait because changes in temperature, rainfall, and humidity can increase parasite prevalence and distribution. Parasite-resistant animals generally have lower parasite burdens and fecal egg counts, stronger immune responses, and better ability to maintain growth, reproduction, and production despite infection. Indigenous sheep and goat breeds are valuable genetic resources because many have naturally developed resistance to gastrointestinal nematodes and ectoparasites. Therefore, selection for parasite resistance can reduce production losses, improve animal welfare, decrease anthelmintic use, and help combat anthelmintic resistance, contributing to sustainable and climate-resilient livestock production (Hoste et al., 2023; Mrode et al., 2024; Sejian et al., 2022).

**5. Feed Efficiency**

Feed efficiency is the ability of an animal to convert feed nutrients into products such as meat, milk, eggs, or growth with minimum feed intake. It is important for both economic and climate-resilient livestock production because efficient animals require less feed, reduce feeding costs, methane emissions, nutrient losses, and greenhouse gas emissions, and can maintain productivity better during feed shortages. A key measure is Residual Feed Intake (RFI), which is the difference between an animal's actual feed intake and its expected intake for maintenance and production; lower RFI indicates better feed efficiency. Therefore, selection for improved feed efficiency enhances profitability, resource-use efficiency, and environmental sustainability (Berry & Crowley, 2023; de Haas et al., 2024; Mrode et al., 2024).

**6. Water-Use Efficiency**

Water-use efficiency is the ability of livestock to use available water effectively while maintaining normal physiological functions, health, reproduction, and productivity under water scarcity. It is an important climate-resilience trait because rising temperatures and frequent droughts are increasing water shortages. Animals with better water-use efficiency require less water for maintenance and production, minimize water loss, and can maintain feed intake, growth, milk production, and reproductive performance during water stress. Indigenous breeds adapted to harsh, water-limited environments often possess superior water-use efficiency. Therefore, improving this trait through breeding and management can conserve freshwater resources, maintain productivity during drought, and enhance sustainable livestock production (Sejian et al., 2022; FAO, 2023; Mrode et al., 2024).

**B. Productive Traits -** Productive traits determine the economic performance of livestock under climate stress conditions.

**1. Milk Yield Under Heat Stress**

Climate-resilient dairy animals can maintain milk production, feed intake, thermoregulation, and metabolic functions during heat stress, thereby reducing production losses and improving herd resilience. Modern breeding programs therefore combine milk yield with heat-tolerance traits using selection indices, genomic selection, and precision phenotyping. This approach improves farm profitability, food security, and the sustainability of dairy production under climate change (Carabaño et al., 2019; Pryce et al., 2022).

**2. Growth Rate**

It is an important economic trait in meat-producing livestock and can be adversely affected by climate change, particularly heat stress, through reduced feed intake, altered metabolism, and increased maintenance requirements. Climate-resilient animals maintain better growth, nutrient utilization, muscle development, and feed conversion efficiency under stressful conditions. Therefore, selection for growth performance under adverse climatic conditions can identify animals with greater adaptability, improve meat production efficiency, reduce climate-related losses, and enhance the sustainability and profitability of livestock production (Hayes et al., 2021; Mrode et al., 2023).

**3. Reproductive Performance**

Reproductive efficiency is highly sensitive to climate stress, as elevated temperatures can disrupt hormonal balance, reduce gamete quality, impair conception, and increase embryonic losses. Climate-resilient animals maintain better reproductive performance under heat stress, including regular estrous cycles, higher conception rates, improved semen quality, and lower embryonic mortality. Therefore, selecting animals with superior fertility under stressful conditions can improve lifetime productivity, genetic progress, herd replacement, and economic efficiency, contributing to sustainable livestock production under changing climatic conditions (Hansen, 2020; Carabaño et al., 2019).

## Genetic Basis of Climate Resilience in Livestock

Climate resilience in livestock refers to the ability of animals to maintain health, reproduction, and production under challenging environmental conditions such as heat stress, drought, diseases, and poor-quality feed. The genetic basis of climate resilience depends on three major factors: **genetic variation among breeds, heritability of adaptive traits, and genotype × environment (G×E) interactions**.

**1. Genetic Variation Among Breeds**

Genetic variation refers to the differences in genes that exist among different breeds and individuals. These genetic differences determine how animals respond to environmental stresses. Different livestock breeds have evolved under different climatic conditions and therefore possess unique adaptive characteristics.

**Examples**

- Indigenous cattle breeds such as Sahiwal, Gir, and Tharparkar are more tolerant to high temperatures and tropical diseases than many exotic breeds.
- Indigenous sheep and goat breeds are often better adapted to drought and feed scarcity.

**2. Heritability of Adaptive Traits**

Heritability is the proportion of observed variation in a trait that is controlled by genetic factors and can be passed from parents to offspring. Traits with moderate to high heritability can be improved through selective breeding.

**Examples**

- Rectal temperature and respiration rate during heat stress show low to moderate heritability.
- Resistance to mastitis and tick infestation has a genetic component.
- Heat tolerance genes such as **SLICK**, **HSP70**, and **HSF1** contribute to thermotolerance.

### 3. Genotype × Environment (G×E) Interactions

Genotype × Environment interaction occurs when the performance of animals with different genetic backgrounds changes across different environmental conditions.In simple terms, an animal that performs best in one environment may not perform best in another environment.

**Example**

A high-producing dairy cow may perform exceptionally well in a cool climate with abundant feed but may experience severe production losses under tropical heat stress.

Similarly:

- Exotic breeds often perform well under intensive management.
- Indigenous breeds may outperform exotic breeds under harsh climatic conditions.

### Selection Strategies for Climate Resilience in Livestock

Climate-resilient livestock breeding aims to develop animals that can maintain productivity, reproduction, health, and welfare under environmental stresses such as heat, drought, feed scarcity, and emerging diseases. Selection strategies have evolved from conventional phenotypic approaches to advanced genomic technologies that enable faster and more accurate genetic improvement.

### 1. Conventional Selection Methods

#### A. Phenotypic Selection

Phenotypic selection is a conventional breeding method that involves selecting animals based on observable characteristics such as milk yield, growth rate, fertility, heat tolerance, disease resistance, coat characteristics, respiration rate, and other measurable traits. In the context of climate resilience, animals that maintain superior performance under environmental stressors such as high temperatures, drought, and disease challenges are chosen as breeding stock. For example, dairy cows that sustain milk production during heat stress, indigenous cattle with lower rectal temperatures and respiration rates under high Temperature–Humidity Index (THI) conditions, and sheep capable of maintaining body weight during drought are considered desirable candidates for selection. Common phenotypic indicators of climate resilience include heat tolerance coefficients, rectal temperature, sweating rate, feed efficiency under heat stress, and disease incidence. The major advantages of phenotypic selection are its simplicity, low cost, and applicability in smallholder and resource-limited production systems where advanced genetic technologies may not be available. However, its effectiveness can be limited because phenotypic performance is influenced by environmental factors, accuracy is lower for traits with low heritability, and favorable genetic variants cannot be identified before trait expression. Despite these limitations, phenotypic selection remains a fundamental tool for improving climate resilience in livestock, particularly in developing countries where genomic resources and infrastructure are still limited (Carabaño et al., 2019; Mrode et al., 2023).

#### B. Pedigree Selection

Pedigree selection is a conventional breeding method that utilizes information on the performance of an animal's ancestors, siblings, and other relatives to estimate its breeding value and genetic potential. The underlying principle is that animals originating from families with superior adaptive and productive traits are more likely to inherit favorable genes associated with those characteristics. In climate-resilient livestock breeding, pedigree selection is used to identify and select animals from bloodlines known for superior heat tolerance, disease resistance, drought adaptation, and the ability to maintain productivity under environmental stress. This approach enables breeders to make selection decisions early in an animal's life, even before the target traits are fully expressed, making it particularly useful when direct phenotypic records are limited or unavailable. However, pedigree selection has lower accuracy than modern genomic methods because it relies on expected genetic relationships rather than actual DNA information, and it cannot identify specific genes or genomic regions responsible for adaptive traits. Despite these limitations, pedigree-based evaluation has played a crucial role in genetic improvement programs and provided the foundation for the development of modern genetic evaluation systems, including genomic estimated breeding values (GEBVs), which are now widely used for enhancing climate resilience in livestock populations (Falconer & Mackay, 1996; Mrode, 2014; Mrode et al., 2023).

### C. Progeny Testing

Progeny testing is a breeding evaluation method in which the genetic merit of a breeding animal, particularly a sire, is assessed based on the performance of its offspring. The process involves selecting breeding males, producing a sufficient number of progeny, recording offspring performance for target traits, and estimating the sire's breeding value. In climate-resilient livestock breeding, progeny testing is used to evaluate traits such as heat tolerance, fertility under thermal stress, disease resistance, survival, and longevity. Because offspring performance reflects the genetic contribution of the parent, progeny testing provides highly accurate estimates of breeding value and is especially valuable for sex-limited traits such as milk production in dairy cattle. However, the method is costly, labor-intensive, and requires a long generation interval before reliable evaluations can be completed. Despite these limitations, progeny testing served as the gold standard for genetic evaluation in dairy breeding programs and laid the foundation for modern genomic selection systems (Mrode, 2014; Hayes et al., 2021).

## 2. Modern Selection Approaches

Modern genomic technologies enable direct selection of adaptive genes and genomic regions associated with climate resilience.

### A. Marker-Assisted Selection (MAS)

Marker-Assisted Selection (MAS) is a molecular breeding approach that uses DNA markers linked to specific genes or Quantitative Trait Loci (QTLs) associated with economically important traits. Unlike conventional selection methods that rely primarily on observable phenotypes, MAS enables breeders to identify animals carrying favorable alleles at an early age through genotyping. The process involves identifying genetic markers associated with adaptive traits, genotyping breeding candidates, and selecting individuals that possess desirable genetic variants. This approach increases selection accuracy and accelerates genetic improvement by allowing breeders to make decisions before the target trait is expressed. MAS is particularly valuable for traits that are difficult, expensive, or time-consuming to measure and for traits with low heritability, where environmental influences can obscure genetic differences among animals (Dekkers, 2004; Boichard & Brochard, 2012).

MAS has been applied to improve traits such as heat tolerance, disease resistance, tick resistance, and feed efficiency. For example, genes belonging to the heat shock protein family, particularly **HSP70**, are associated with cellular protection against thermal stress, while several markers linked to disease and parasite resistance have been identified in livestock populations. A notable example is the **SLICK** gene, which produces a short, sleek hair coat that enhances heat dissipation and thermoregulation in cattle. Animals carrying the SLICK allele exhibit lower body temperatures and improved productivity under hot climatic conditions, making this gene an important target in breeding programs for tropical and subtropical regions. Although MAS has proven effective for traits controlled by a few major genes, its application is more limited for complex climate-resilience traits that are influenced by many genes with small individual effects, for which genomic selection is generally more effective (Dikmen et al., 2014; Hayes et al., 2021).

### B. Genomic Selection (GS)

Genomic Selection (GS) is an advanced breeding approach that uses thousands of genome-wide SNP markers to predict the genetic merit of animals. Unlike Marker-Assisted Selection (MAS), which mainly focuses on a few markers linked to major genes, GS uses information from the entire genome and captures the effects of both major and minor genes. The predicted genetic merit is expressed as a Genomic Estimated Breeding Value (GEBV). By genotyping animals at an early age, GS allows early and accurate selection of superior breeding animals, reducing generation interval and accelerating genetic progress (Meuwissen et al., 2001; Hayes et al., 2021). GS is particularly useful for improving complex climate-resilience traits such as heat tolerance, disease resistance, fertility, feed efficiency, water-use efficiency, and methane efficiency, which are controlled by many genes. Major genomic approaches include GBLUP and Bayesian models (BayesA, BayesB and BayesCπ). By combining genomic, pedigree, and phenotypic information, GS can improve the accuracy and rate of genetic gain and help develop productive, climate-resilient, and environmentally sustainable livestock populations (VanRaden, 2008; Carabaño et al., 2019; Mrode et al., 2023; Hayes et al., 2021).

**C. Genome-Wide Association Studies (GWAS)**

Genome-Wide Association Study (GWAS) is a genomic tool used to identify associations between genome-wide genetic variants, mainly SNPs, and economically important traits in livestock. Unlike candidate-gene studies, GWAS examines thousands to millions of SNPs across the entire genome to identify genomic regions and candidate genes influencing complex traits. It involves phenotyping animals, genotyping them, statistical association analysis, and identification of significant SNPs or candidate genes (Hayes & Goddard, 2010; Utsunomiya et al., 2022). GWAS is useful for identifying the genetic basis of heat tolerance, disease resistance, feed and water-use efficiency, fertility, and other climate-resilience traits. It can reveal genes such as HSP70, HSP90, and HSF1 associated with heat-stress responses. The identified SNPs and candidate genes can subsequently be used in MAS and genomic selection (GS) to improve climate resilience. However, GWAS requires large, well-characterized populations and accurate phenotypic and genomic data for reliable results (Carabaño et al., 2019; Mrode et al., 2023; Utsunomiya et al., 2022).

**D. Precision Lvestock Breeding**

Precision livestock breeding is a modern breeding approach that combines genomics, artificial intelligence (AI), sensors, big-data analytics, and environmental monitoring to improve the accuracy of animal selection. It uses precision phenotyping to continuously measure traits such as body temperature, respiration rate, feed and water intake, activity, milk yield, and health status. Sensors such as wearable devices, smart collars, accelerometers, infrared thermography, and automated weighing systems provide real-time information on animal performance and response to environmental stress (Berckmans, 2017; Koltes et al., 2019).

AI and machine-learning tools can then integrate sensor data with genomic information to identify animals with better heat tolerance, disease resistance, feed and water efficiency, and overall climate resilience. Thus, precision breeding enables early and accurate selection of resilient animals, improves breeding-value prediction, animal welfare, productivity, and resource-use efficiency, and supports sustainable livestock production under changing climatic conditions (Caja et al., 2016; Mrode et al., 2023; Tullo et al., 2019).

**Important climate resilient gene**

| Gene | Main role in heat tolerance | Important effect |
|---|---|---|
| HSP70 | Heat-shock protein; protects cellular proteins from heat damage | Cellular protection and recovery |
| HSP90 | Heat-shock protein involved in protein stability | Maintains cellular function during heat stress |
| SLICK (PRLR) | Produces short, sleek hair coat | Better heat dissipation and lower body temperature |
| HSF1 | Regulates expression of heat-shock proteins | Activates cellular heat-stress response |
| HSP27 (HSPB1) | Protects cells against thermal and oxidative stress | Enhances cellular stress tolerance |
| HSPA1A | Major inducible heat-shock protein | Protects proteins during acute heat stress |

**Role of Indigenous Breeds in Climate-Smart Livestock Production**

Indigenous breeds are valuable components of climate-smart livestock systems because of their genetic adaptation to local environmental stresses. They generally exhibit superior thermotolerance through efficient thermoregulation, including sweating, panting, and heat dissipation, as observed in adapted breeds such as Gir and Sahiwal. They also possess greater disease and parasite resistance and can efficiently utilize low-quality feeds and crop residues during periods of feed scarcity. Their tolerance to water and nutritional stress, maintenance of reproductive performance under heat stress, and lower dependence on external inputs enhance their suitability for low-input production systems. Furthermore, indigenous breeds constitute important reservoirs of adaptive genetic diversity for heat tolerance, disease resistance, and stress adaptation, which can be exploited through selective and genomic breeding. Strategic crossbreeding, such as Holstein Friesian × Sahiwal, can combine high production potential with adaptive traits, thereby contributing to the development of productive, resilient, and climate-smart livestock populations.

**Challenges in Livestock Breeding for Climate Resilience**

**1.** **Low heritability:** Adaptive traits are complex and strongly influenced by environmental factors, slowing genetic improvement.

**2.** **Difficult phenotyping:** Resilience traits require accurate, long-term measurements and specialized equipment.

**3.** **Limited genomic information**: Genomic resources for many indigenous breeds remain inadequate.

**4.** **Productivity–resilience trade-off:** Selection for high production may compromise environmental adaptability.

**5.** **Loss of genetic diversity:** Replacement and indiscriminate crossbreeding can lead to loss of valuable adaptive genes.

**6.** **Emerging diseases:** Climate change alters pathogen and parasite distribution, creating new selection challenges.

**7.** **Long generation interval:** Slow reproductive cycles, particularly in cattle and buffalo, delay genetic progress.

**8.** **High technology costs**: Genomic selection and precision phenotyping require substantial investment.

**9.** **Limited infrastructure:** Inadequate recording systems, laboratories, data facilities, and skilled personnel restrict implementation.

**Conclusion**

✓ **Breeding for climate resilience is a sustainable and cost-effective solution** that improves animals' ability to adapt to environmental stresses.
✓ **Indigenous breeds are valuable genetic resources** because they possess natural traits such as heat tolerance, disease resistance, and adaptability.
✓ **Modern genomic tools** such as genomic selection, GWAS, and marker-assisted breeding help identify and select resilient animals more accurately and rapidly.
✓ **Combining conventional breeding with advanced technologies** will enable the development of climate-smart livestock that maintain productivity, health, and welfare under future climate conditions.

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