



Evolving Animal Breeding Strategies for Viksit Bharat @2047: Towards Productive, Climate-Resilient and Sustainable Livestock Systems

***Vivek Kumar Singh, Sanchitpal Singh, Umashankar Rawat, Vineet Kumar Pandey,
Rohit Solanki and Amritanshu Upadhyay**

**PhD Scholars, ICAR-Indian Veterinary Research Institute (IVRI), Izatnagar,
Bareilly, Uttar Pradesh, India**

***Corresponding Author's email: vivekvet02@gmail.com**

The vision of Viksit Bharat @2047 requires an agricultural and livestock sector that supports nutritional security, farmers' incomes, technological advancement, environmental sustainability and rural economic development. Animal breeding is central to this transformation because genetic improvement determines the long-term potential of livestock for production, reproduction, health, feed utilisation and adaptation to changing environmental conditions. Yet breeding programmes that prioritise a narrow range of production traits may inadequately address climate change, feed scarcity, disease burden, biodiversity conservation and the socioeconomic diversity of Indian livestock systems. The transition towards sustainable livestock development therefore requires a shift from production-centred selection to balanced, multi-trait breeding strategies incorporating productivity, fertility, longevity, disease resistance, heat tolerance, feed efficiency and environmental performance. Genomic selection, artificial insemination, embryo technologies, reproductive biotechnology and digital phenotyping offer opportunities to accelerate genetic gain when supported by reliable performance recording, representative reference populations and effective institutional delivery. Indigenous breeds and locally adapted genetic resources must remain integral to national strategies, while crossbreeding and breed upgrading should be guided by defined objectives and agroclimatic suitability. The NITI Aayog report Scenarios Towards Viksit Bharat and Net Zero, Sectoral Insights: Agriculture (2026) identifies breed improvement, animal nutrition, feed efficiency and a higher proportion of lactating bovines as contributors to long-term productivity and mitigation co-benefits. This chapter examines how breeding policies and programmes can evolve, and proposes an integrated framework combining genetic improvement, climate resilience, conservation, precision livestock management and farmer participation.

Keywords: animal breeding; Viksit Bharat; genomic selection; indigenous breeds; climate resilience; genetic gain; livestock sustainability; feed efficiency.

Introduction

The development of a prosperous and technologically advanced India by 2047 depends partly on transforming agriculture and allied sectors. Livestock contributes to food and nutritional security, employment, household income, manure availability, risk diversification and rural economic participation. Dairy cattle, buffaloes, sheep, goats, pigs and poultry perform different functions across India's diverse agroecological and socioeconomic environments. Livestock development therefore requires breeding and management strategies tailored to species, breeds, production systems and farmer priorities rather than a uniform production model.

Animal breeding provides a long-term mechanism for changing the genetic composition of populations. Improvements in milk yield, growth, reproduction, health and product quality can increase output from existing resources. However, genetic improvement is not synonymous with maximising a single production trait. Animals with high genetic potential may fail to express it under inadequate nutrition, heat stress, poor disease control or insufficient veterinary support. Selection for higher production without adequate attention to fertility, longevity and adaptation may increase management requirements and undermine profitability, particularly in smallholder systems.

The development agenda consequently requires breeding objectives that integrate economic productivity, resilience, environmental performance and farmer capacity to adopt improved animals and technologies. FAO (2010) recommends that breeding strategies be based on explicit development objectives, the matching of genetic resources to production environments, and the sustainable management of animal genetic resources. The NITI Aayog report (2026) applies an adaptation-first approach to agricultural pathways and assesses how productivity, resilience and resource efficiency can also deliver mitigation co-benefits. It assumes average productivity of in-milk bovines of 15 kg per animal per day by 2070 under its Net Zero Scenario, compared with 12 kg under the Current Policy Scenario. These are modelled scenario assumptions, not guaranteed forecasts. They nevertheless demonstrate the importance assigned to coordinated interventions in genetics, nutrition and management.

This chapter argues that animal breeding must evolve from a predominantly production-oriented activity into an integrated strategy for sustainable livestock development. The objective should be animals that are productive, reproductively efficient, healthy, resilient to environmental stress and compatible with the feed resources and management systems available to farmers.

Reorienting breeding objectives towards balanced genetic improvement

Moving beyond single-trait selection

Selection programmes have often concentrated on traits such as milk yield, body weight, growth rate or egg production because these traits are measurable and economically important. Yet excessive emphasis on a single trait can create unfavourable correlated responses. In dairy systems, selection for yield without simultaneous attention to fertility, udder health, productive lifespan and feed efficiency can increase replacement costs and management demands. In resource-constrained systems, the highest-yielding genotype is not necessarily the most profitable or resilient. Future breeding objectives should use multi-trait selection indices combining production, reproduction, health, longevity, adaptation and economic efficiency. For dairy cattle and buffaloes, relevant traits include lactation yield and persistency, age at first calving, calving interval, conception rate, productive lifespan, mastitis resistance and feed efficiency. In sheep and goats, growth, litter size, maternal ability, survival and parasite resistance may be important; poultry programmes should combine egg or meat output with feed conversion, fertility, survivability, health and thermal tolerance. Selection indices should account for feed, veterinary, reproductive and replacement costs. The objective is not simply to maximise biological output, but to improve net economic value while maintaining animal health and system resilience. Breeding goals should be revisited periodically as market prices, climate risks, feed availability and farmers' priorities change.

Functional and adaptive traits

Heat tolerance, disease resistance, fertility under nutritional stress, survival and longevity are increasingly important. Their improvement requires consistent phenotyping and long-term recording. Fertility evaluation, for example, requires insemination dates, conception outcomes, calving intervals, pregnancy losses and reproductive-disorder records. Health-related selection requires standardised records of disease incidence, treatment and survival. Where direct measurement is costly, validated indicator traits may be used, but their genetic relationships with target traits must be established. Functional traits can have substantial economic value in smallholder systems, where infertility, mortality and repeated veterinary

treatment impose direct costs. Improving robustness and productive lifespan can reduce replacement requirements and improve lifetime output per animal.

Indigenous genetic resources and context-specific breeding

Conservation as a development investment

India's livestock diversity includes indigenous cattle and buffalo breeds, sheep and goat populations, and locally adapted poultry and other genetic resources. These populations have been shaped by diverse climates, feeding systems, disease pressures and management practices. Their characteristics can be valuable for heat tolerance, survival, reproductive performance and the utilisation of locally available feed. Genetic diversity is not merely a heritage concern; it is an option value for future adaptation. Conservation should combine breed identification, population monitoring, pedigree and performance recording, and maintenance of adequate genetic diversity. Cryoconservation of semen and embryos can complement in situ conservation, while viable breeding populations should be maintained in their production environments with farmer participation and appropriate incentives. FAO (2007, 2015) highlights the need to sustainably use and conserve animal genetic resources.

Matching breeds to production environments

Breeding decisions should account for genotype-by-environment interactions. High-producing exotic or crossbred animals may perform well where nutrition, cooling, veterinary care and reproductive management are reliable. Locally adapted animals may be advantageous under low-input conditions or in regions with high thermal stress and variable feed supply. The suitable strategy can therefore differ among regions and farming systems. Crossbreeding can combine complementary traits and exploit heterosis, but indiscriminate crossing may dilute locally adapted genetic resources or produce animals whose nutritional and management requirements exceed farmers' capacity. Programmes should specify target populations, mating structures, desired breed composition, replacement strategies and safeguards for genetic diversity. Purebreeding, crossbreeding and upgrading should be selected on evidence of long-term performance, not treated as universally interchangeable options.

Genomic selection and precision breeding

Genomic information and genetic gain

Genomic selection uses genome-wide marker information alongside phenotypes and pedigree data to estimate genomic breeding values. Meuwissen et al. (2001) established a foundational framework for predicting total genetic merit from dense marker maps. Hayes et al. (2009) reviewed its application in dairy cattle. Because candidates can be evaluated before they complete their own production records or generate offspring, genomic selection can improve selection accuracy at young ages and reduce generation intervals, provided suitable reference populations and evaluation systems exist. Applications can extend beyond production to fertility, longevity, disease resistance, feed efficiency and adaptation-related traits. Saravanan et al. (2023) reviewed livestock genomics in India and discussed its applications in genetic diversity assessment, identification of important variants and genomic selection, while highlighting the need for infrastructure and wider implementation.

Establishing Indian reference populations

Genomic prediction equations are not automatically transferable between breeds or production systems. Differences in allele frequencies, linkage disequilibrium, genetic relationships, trait definitions and management can reduce prediction accuracy. A national approach should build representative reference populations for important indigenous breeds, crossbred cattle, buffaloes and other economically significant species. High-quality genotypes should be linked to standardised phenotypes, pedigree and management information. Data collection should prioritise economically important traits that are difficult to improve through conventional selection alone, including fertility, productive lifespan, disease resistance and feed efficiency. Reference populations should represent diverse regions and management systems. Genomic selection complements rather than replaces

performance recording: without reliable phenotypes, independent validation and diversity monitoring, genomic predictions may be inaccurate or fail to deliver sustained gain.

Reproductive technologies and genetic safeguards

Artificial insemination, sex-sorted semen, embryo transfer and in-vitro fertilisation can accelerate the dissemination of desirable genetics when integrated with genetic evaluation. However, intensive use of a small number of elite sires can increase inbreeding and reduce effective population size. Genomic relationship information, planned matings and constraints on inbreeding should therefore be incorporated into selection and dissemination programmes. Reproductive technologies should be evaluated on cost, conception outcomes, welfare, field accessibility and service capacity, rather than introduced as stand-alone interventions.

Climate-resilient and low-emission breeding

Heat tolerance and environmental robustness

Rising temperatures and climatic variability can reduce feed intake, milk yield, fertility and survival, and may increase disease risks. Breeding for heat tolerance should use measurable and validated indicators, including body temperature, respiration rate, production stability, fertility during hot periods and survival under thermal stress. Physiological records can be combined with weather and performance data to identify animals that maintain function under heat exposure. Multi-environment evaluation is important because animals ranked highly in temperate or well-controlled environments may not retain the same ranking in hot, humid or resource-constrained conditions. The aim is not to improve heat tolerance at the expense of productivity, but to select animals combining acceptable production with stable performance in their target environments.

Feed efficiency and emissions intensity

Genetic improvement can contribute to climate mitigation when animals produce more milk, meat or eggs over their productive lives without proportional increases in feed use and emissions. Nevertheless, higher productivity does not automatically reduce total emissions: additional output may require more feed or changes in herd structure. Breeding objectives should therefore be evaluated alongside feed intake, lifetime productivity, animal numbers and appropriate emission indicators. Residual feed intake and direct methane measurements are potential research areas, although methane phenotyping is technically demanding and proxy traits require validation in target populations. The IPCC (2019) provides methods for estimating emissions from livestock and manure management. Farm-level evaluation requires appropriate activity data and emission factors. The objective should be to improve whole-system efficiency rather than assume that selection for production alone guarantees a specific reduction in emissions.

Genetics integrated with nutrition and health

Genetic potential is expressed through interaction with feed, water, health and management. Breeding should therefore be coordinated with ration balancing, fodder development, preventive veterinary care and reproductive management. The NITI Aayog (2026) report emphasises the relationship between genetic potential, feed and fodder quality, health and agroclimatic conditions. It recommends breed improvement alongside nutrition, health and feed-efficiency interventions. Improved feed quality, balanced rations and better utilisation of crop residues can help animals express their genetic potential. Silage, fodder banks and arrangements for moving feed resources from surplus to deficit regions can help address seasonal and spatial shortages. Breeding programmes should estimate the nutritional requirements of candidate genotypes and avoid promoting animals whose requirements exceed the resources available to target farmers.

Species-specific breeding priorities

Cattle and buffaloes

Dairy breeding should combine milk yield with fertility, udder health, longevity, heat tolerance and feed efficiency. Indigenous cattle, crossbred cattle and buffaloes should be evaluated using objectives appropriate to their production environments. Increasing the

proportion of productive lactating animals requires improvements in fertility, animal health, timely breeding and dry-period management. Selection should favour animals that maintain reproductive and productive performance over successive lactations.

Sheep and goats

Small ruminants are important in arid, semi-arid, mountainous and resource-constrained regions. Breeding goals should reflect production purposes, including meat, milk, wool, fibre and reproductive performance. Selection for growth should be balanced with maternal ability, survival, parasite resistance, reproductive regularity and utilisation of local vegetation. Community-based breeding programmes can enable farmers to identify superior animals while maintaining diversity and adapting goals to local priorities.

Pigs and poultry

Pig breeding should integrate growth, feed conversion, litter size, maternal performance, survivability and disease resistance. Poultry objectives should reflect intensive commercial, backyard or dual-purpose systems. In backyard poultry, adaptation, survival, disease resistance and ability to utilise locally available feed may be as important as egg output and growth. In commercial systems, feed efficiency, reproductive performance, welfare and health remain central. Species and production-system differences preclude a single national selection index.

Institutions, data and farmer participation

Performance recording and digital infrastructure

Reliable genetic improvement depends on standardised data for pedigree, production, reproduction, health, survival and management. Digital identification, mobile recording, automated milk measurement and electronic breeding databases can improve completeness and timeliness. Interoperability across breeding organisations, veterinary services and research institutions is desirable, with quality control and appropriate safeguards for privacy and access. Recording must remain practical for farmers and field staff.

Participatory and inclusive breeding

Smallholders should help define breeding objectives. Priorities may include regular income, low maintenance requirements, reproductive reliability, reduced disease risk and compatibility with local feed. Participatory breeding can improve adoption, while cooperatives, producer organisations, breed societies and local institutions can support performance recording and access to breeding services. Extension and training should reach women and others responsible for day-to-day animal care.

Aligning research, extension and investment

Genetic improvement requires sustained investment because population-level change occurs over generations. Distribution of improved animals without performance recording, replacement plans or genetic evaluation may produce limited long-term gain. Research institutions, breeding organisations, veterinary universities, government departments and service providers should agree on measurable breeding goals and evaluate results. Extension should explain mating decisions, inbreeding risks and the importance of matching animal requirements to available resources.

A strategic roadmap for Viksit Bharat @2047

A phased approach can connect immediate improvements with long-term genetic progress. The following roadmap is a proposed synthesis for implementation; it is not a timetable prescribed by the NITI Aayog report. Phase I, Build the foundations: characterise populations, standardise performance recording, identify production constraints and establish region-specific breeding objectives. Audit current programmes for genetic gain, reproduction, diversity and farmer participation. Phase II, Accelerate balanced improvement: introduce genomic selection where reliable phenotypes and reference populations exist; integrate artificial insemination, progeny testing, structured crossbreeding and reproductive technologies according to species and delivery capacity.

Phase III, Integrate resilience and environmental performance: include validated indicators of heat tolerance, disease resistance, longevity, feed efficiency and environmental performance. Evaluate genetic merit across relevant agroclimatic regions. Phase IV, Monitor outcomes and adjust: assess annual genetic gain, fertility, productive lifespan, disease incidence, inbreeding, feed efficiency, profitability and performance under heat stress. Use environmental indicators where suitable data and validated methods are available. The roadmap should remain adaptive. Breeding priorities must change as scientific evidence improves, climatic conditions shift and farmers' economic requirements evolve.

Challenges and research priorities

Constraints include incomplete phenotypic records, limited breed-specific genomic reference populations, weak integration of health and reproduction data, uneven access to reproductive technologies and inadequate coordination between genetic improvement and management. Advanced technologies may not be cost-effective for every population; adoption should be based on expected genetic gain, cost-effectiveness and delivery capacity. Research priorities include estimating genetic parameters for fertility, heat tolerance, disease resistance, feed efficiency and productive lifespan in Indian populations; investigating genotype-by-environment interactions and inbreeding; and quantifying the economic consequences of alternative breeding goals. More evidence is also needed on whether genetic improvement reduces emissions intensity under Indian feeding and management conditions. Longitudinal farm studies can examine whether productivity and efficiency gains are achieved without compromising welfare or farmer profitability. Breeding programmes should also be assessed for distributional consequences. An intervention that raises average output but excludes smallholders, erodes adapted genetic resources or increases dependence on unaffordable inputs may not deliver inclusive development. Scientific progress must be matched by institutions that support equitable access and long-term sustainability.

Conclusion

Viksit Bharat @2047 calls for an animal breeding paradigm combining genetic progress with climate resilience, economic viability, nutritional security and conservation of animal genetic resources. Selection for production remains important, but must be integrated with fertility, longevity, disease resistance, heat tolerance and feed efficiency. Indigenous and locally adapted populations should be treated as strategic resources, while crossbreeding and reproductive technologies should be applied according to defined objectives and production-system requirements. Genomic selection, digital phenotyping and reproductive biotechnology can accelerate genetic gain, but success depends on reliable records, representative reference populations, effective extension and safeguards against excessive inbreeding. Genetic potential must also be integrated with nutrition, health care, fodder development and environmental assessment. India therefore needs a coordinated, evidence-based and farmer-oriented breeding framework. By moving from narrow production targets towards balanced, context-specific genetic improvement, animal breeding can contribute to a more productive, resilient, inclusive and environmentally responsible livestock sector.

Translating breeding goals into measurable national outcomes

A national breeding framework should translate broad development ambitions into indicators that can be measured consistently and compared across time. Each programme should specify a baseline, target population, selection objective, delivery pathway and review interval. Genetic trends should be separated from changes caused by nutrition, housing, disease control and other management improvements wherever the data permit. This distinction is important because improved farm output alone does not establish that genetic merit has increased. Periodic genetic evaluation and independent programme audits can identify whether expected gains are being realised and whether unintended effects are emerging. A balanced monitoring dashboard could include annual genetic trends for production and functional traits; age at first calving and calving interval; survival and productive lifespan;

disease incidence; feed consumed per unit of product; inbreeding rate; and participation by smallholders and women. Environmental indicators, including emissions intensity, should be included only where measurement methods and data quality are sufficiently robust. The dashboard should not encourage selection for one easily measured indicator at the expense of other traits that matter for welfare, profitability or resilience. The design of incentives is equally important. Breeding organisations and service providers should be rewarded for sustained outcomes, such as improved conception, verified genetic progress, reliable recording and responsible management of genetic diversity, rather than only for the number of inseminations, doses distributed or animals enrolled. Such output-based accountability can encourage better service quality while allowing regional flexibility. Independent evaluation should examine both average results and who benefits, because aggregate gains can conceal poor access among remote communities or resource-poor households. Finally, a national framework should support open scientific collaboration while protecting farmers' data and recognising the contributions of public research institutions and breed custodians. Common trait definitions, interoperable data standards and transparent methods for estimating breeding values can make evaluations more comparable. Access to genomic tools should be linked to training, affordable services and long-term maintenance of reference populations. This approach would help ensure that technological advances are embedded in durable institutions rather than remaining isolated pilot projects.

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