Prof. M.R. Srinivasan Memorial Oration

Advanced Reproductive Biotechnologies for Multiplication of Superior Animals, Genetic Improvement and Conservation*

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Introduction

India is progressing toward the vision of *Viksit Bharat* 2047, which aims to transform the country into a developed nation by the centennial year of independence. Agriculture and allied sectors play a vital role in achieving this goal. The agricultural sector contributes nearly 18% to the national GDP and provides employment to about 50% of the workforce. Within this sector, livestock and dairying play a crucial role in sustaining rural livelihoods and ensuring nutritional security. India is currently the largest producer of milk in the world, contributing almost 25% of global milk production, with total production estimated at 247.87 million tonnes during 2024-25. Per capita milk availability has also increased significantly from 319 g/day in 2014-15 to 485 g/day in 2024-25. Despite these achievements, the productivity per animal in India remains relatively low compared to developed countries. The average milk yield per animal in India is around 2079 kg per lactation, whereas countries such as the United States produce more than 10,000-12,000 kg per lactation. This productivity gap highlights the urgent need to improve the genetic potential of livestock. Advanced reproductive biotechnologies, also known as Assisted Reproductive Technologies (ARTs), offer powerful tools to accelerate genetic improvement, multiply elite animals, and conserve valuable indigenous breeds.

Challenges in Livestock Productivity in India

Despite being the largest milk producer in the world, India faces several challenges that limit the productivity of its livestock population. These challenges include low milk productivity, the large number of non-productive animals, and the high incidence of reproductive disorders. Addressing these constraints is essential for improving the efficiency and sustainability of the dairy sector. One of the major concerns in the Indian dairy sector is the relatively low milk productivity of indigenous cattle. Although there has been a gradual improvement over the years, the average milk yield of indigenous cattle still remains significantly lower compared to global standards. Recent estimates indicate that indigenous cattle produce around 1,292 kg of milk per lactation, which is an improvement from approximately 927 kg recorded in 2014-15. However, this level of production is still much lower than that observed in leading dairy-producing countries. The productivity gap is influenced by multiple factors including nutritional deficiencies, poor management practices, and environmental stress.

Feed and fodder shortages represent one of the most important constraints affecting livestock productivity. India currently faces a green fodder deficit of about 35.6%, along with a shortage of concentrate feed of nearly 25%. In addition, poor mineral nutrition further limits the productive potential of animals. Inadequate feeding not only reduces milk yield but also negatively affects reproductive efficiency and overall animal health. Climatic stress is another critical factor influencing dairy productivity. Heat stress, which is common in tropical and subtropical regions, significantly affects livestock performance by reducing feed intake, milk production, and fertility. Studies suggest that heat stress alone can cause a loss of 10-25% in milk yield and reduce conception rates by 20-30%. These environmental challenges are further aggravated by limited adoption of scientific breeding and management practices among smallholder farmers.

Another major issue affecting the livestock sector is the high proportion of non-productive animals in the national herd. A large number of indigenous and nondescript animals produce very little milk, often only 1-2 kg per day, which significantly reduces the overall efficiency of the dairy production system. Estimates indicate that nearly 30-40% of cattle in India are non-milch animals, while about 50-60% of animals in rural herds are considered low productive. Additionally, nondescript breeds constitute nearly 45% of the total cattle population. The presence of such a large number of low-producing animals places an economic burden on farmers, as these animals consume feed and other resources without contributing significantly to farm income. Consequently, improving the genetic potential of livestock through systematic breeding programs and advanced reproductive technologies becomes extremely important.

Reproductive disorders also represent a major constraint to livestock productivity in India. Inefficient reproduction not only delays the birth of calves but also reduces the lifetime productivity of animals. Studies have reported that approximately 30-50% of animals in dairy herds suffer from various reproductive disorders. Among these, anestrus is the most common condition, affecting around 31.79% of animals. Repeat breeding is another significant problem, occurring in about 20-25% of animals. Other reproductive issues include retained fetal membranes, which affect around 10-15% of animals, and abortions, which occur in approximately 5-10% of cases. These reproductive problems are often associated with poor nutrition, inadequate housing, improper management practices, heat stress, and low success rates in artificial insemination programs. In many cases, farmers lack access to proper veterinary services and reproductive health management, which further exacerbates the problem.

Assisted Reproductive Technologies (ARTs) in Livestock Improvement

The ARTs play an increasingly important role in modern livestock production systems by accelerating genetic improvement, enhancing reproductive efficiency, and increasing the overall productivity of farm animals. In countries like India, where the demand for milk and animal products is continuously increasing, these technologies provide powerful tools for the rapid multiplication of superior animals and the conservation of valuable genetic resources. ARTs include several advanced techniques such as artificial insemination, sexed semen technology, in vitro fertilization, ovum pick-up, embryo transfer technology, animal cloning, and genome editing. The integration of these technologies has the potential to significantly enhance the rate of genetic gain while reducing the generation interval, thereby enabling faster dissemination of desirable traits within livestock populations.

Artificial Insemination

Artificial insemination (AI) is one of the most widely used and well-established reproductive technologies in livestock breeding programs worldwide. This technique involves the collection of semen from genetically superior males and its artificial deposition into the reproductive tract of females. AI allows semen from a single superior bull to be used for breeding a large number of females, thereby facilitating the rapid dissemination of superior genetics across large populations. The use of AI offers several advantages, including improved genetic selection, prevention of sexually transmitted diseases, and reduced costs associated with maintaining breeding bulls. In developed countries, artificial insemination is widely adopted, with nearly 80-90 percent of dairy cattle bred through AI programs. However, in India the coverage of artificial insemination remains relatively limited, with only about 40 percent of breedable animals currently covered under AI services. To support the expansion of AI programs, India has developed a substantial infrastructure that includes approximately 56 semen stations, five sex-sorted semen production facilities, and about 25 in vitro fertilization laboratories. These facilities play a crucial role in strengthening breeding programs and accelerating the genetic improvement of livestock populations across the country.

Sex-Sorted Semen Technology

Another important advancement in reproductive biotechnology is sexed semen technology. This technology enables the separation of sperm cells carrying X and Y chromosomes, allowing farmers and breeders to control the sex of the offspring. In dairy farming systems, female calves are generally preferred because they grow into milk-producing cows or buffaloes, making them economically more valuable than male calves. By using sexed semen, it is possible to produce up to 90 percent female calves, which significantly enhances herd expansion and replacement efficiency. This technology also helps reduce the number of unwanted male calves, thereby improving the overall efficiency of livestock production systems. In India, significant progress has been made in the development and use of sex-sorted semen under government initiatives such as the Rashtriya Gokul Mission. Through these efforts, more than 58 lakh doses of sex-sorted semen have already been produced and made available for breeding programs, contributing to the improvement of dairy herd composition and productivity.

In Vitro Fertilization (IVF)

In vitro fertilization (IVF) is another advanced reproductive technology that has gained considerable importance in livestock breeding. IVF involves the fertilization of an oocyte with sperm outside the body under controlled laboratory conditions. The resulting embryos are cultured for a specific period and then transferred into recipient females for further development and gestation. The first IVF calf in the world was produced in 1982, marking a major milestone in animal reproductive biotechnology. In India, the first buffalo calf produced through IVF, named "Pratham," was born in 1990 at ICAR-National Dairy Research Institute, Karnal. IVF technology offers several advantages, including the rapid multiplication of elite females, increased embryo production, and enhanced opportunities for genetic improvement. It also provides a valuable platform for studying embryonic development, gene expression, and reproductive physiology. Despite its potential, the efficiency of IVF remains moderate, with blastocyst development rates generally ranging from 30 to 40 percent, particularly lower in buffaloes compared to cattle.

Ovum Pick-Up (OPU) and IVF

Ovum pick-up (OPU) is another important technique that complements IVF technology. OPU is a minimally invasive procedure used to collect oocytes directly from the ovaries of live animals using ultrasound-guided aspiration. One of the major advantages of this technique is that it allows repeated collection of oocytes from genetically superior donor animals without harming them. The collected oocytes can then be matured, fertilized, and cultured through IVF to produce embryos. This technique significantly increases the reproductive potential of elite animals by enabling multiple embryo production within a short period. India achieved an important milestone with the birth of the first OPU-IVF calf named "Holi" at ICAR-NDRI, Karnal in 2012. The integration of OPU and IVF technologies has opened new possibilities for the rapid multiplication of superior germplasm and the development of high-value livestock.

Embryo Transfer Technology

Embryo transfer technology (ETT) is another important reproductive biotechnology that contributes to genetic improvement in livestock. In this technique, embryos produced from genetically superior donor animals are transferred into recipient females that carry the

Major Achievements in Reproductive Biotechnology in India (Year-wise):

•	1990	Production of 10 calves from a single cow using Embryo Transfer (ET).
•	1991	Birth of the world's first IVF buffalo calf.
•	2009	Production of the world's first cloned water buffalo.
•	2012	Birth of India's first OPU–IVF cow.
•	2017	Birth of a cloned buffalo under field conditions.
•	2019–2020	Production of seven cloned copies from a single bull.
•	2023	Birth of India's first cloned cow.
•	2024	Cloned buffalo Garima produced eight calves during her lifetime.

10 calves from a single cow via ET (1990)

World's first IVF buffalo calf (1991)

World's first cloned water buffalo (2009)

India's first OPU-IVF cow (2012)

Birth of cloned buffalo in the field (2017)

Seven cloned copies from a single bull (2019-20)

Cloned buffalo, Garima, produced 8 calves in lifetime (2024)

India's first cloned cow (2023)

pregnancy to term. The process typically involves several steps, including hormonal stimulation of donor animals to induce superovulation, artificial insemination with semen from superior bulls, recovery of embryos from the donor animal, and transfer of viable embryos into synchronized recipient females. ETT enables a single superior female to produce multiple offspring within a short period, thereby accelerating genetic progress. However, the successful implementation of embryo transfer programs requires skilled personnel, specialized equipment, and proper hormonal management. The conception rate associated with embryo transfer is generally around 50-60 percent, which varies depending on factors such as embryo quality, synchronization protocols, and management conditions.

Animal Cloning

Animal cloning represents one of the most advanced forms of reproductive biotechnology. Cloning involves the production of genetically identical animals through a technique known as somatic cell nuclear transfer. In this process, the nucleus from a donor somatic cell is transferred into an enucleated oocyte whose own genetic material has been removed. The reconstructed embryo is then cultured under laboratory conditions before being transferred into a surrogate mother for further development. Cloning has significant potential for the rapid multiplication of elite animals, conservation of endangered breeds, production of genetically modified animals, and various biomedical applications. In 2009, ICAR-National Dairy Research Institute, Karnal achieved a global milestone by producing the world's first cloned buffalo named "Samrupa" using the handmade cloning technique. Since then, the institute has successfully produced several cloned buffaloes and demonstrated that these animals can grow normally, produce high-quality semen, reproduce successfully, and yield normal quantities of milk. More recently, in 2023, ICAR-NDRI also produced India's first cloned Gir cow named "Ganga," marking a significant advancement in cattle cloning research in the country.

Integration of Reproductive Technologies

The integration of different reproductive technologies offers even greater opportunities for accelerating livestock improvement. For example, combining cloning with OPU-IVF technology allows rapid multiplication of elite animals within a short period. Similarly, the use of sexed semen together with IVF can significantly increase the production of female offspring, which is particularly beneficial in dairy production systems. When these technologies are further integrated with genomic selection approaches, the rate of genetic gain can be substantially enhanced. Such integrated breeding strategies help reduce generation intervals, increase the accuracy of selection, and accelerate the dissemination of superior genetics throughout livestock populations.

Conservation of Indigenous Breeds

In addition to improving productivity, advanced reproductive technologies also play a critical role in the conservation of indigenous livestock breeds. India is home to several valuable indigenous cattle and buffalo breeds such as Sahiwal, Gir, Tharparkar, and Murrah buffalo, which possess unique traits including disease resistance, adaptability to harsh climatic conditions, and efficient utilization of low-quality feed resources. However, many indigenous breeds face the risk of genetic dilution or decline due to indiscriminate crossbreeding and changes in farming systems. Advanced reproductive technologies provide effective tools for conserving these valuable genetic resources. Techniques such as embryo cryopreservation, semen freezing, cloning, and IVF can help preserve elite germplasm and maintain genetic diversity within livestock populations. These technologies also enable the multiplication of rare or endangered breeds and support long-term genetic conservation programs.

Conclusion

Assisted reproductive technologies represent powerful tools for transforming the livestock sector by improving productivity, accelerating genetic progress, and conserving valuable animal genetic resources. Strategic application of these technologies, combined with improved management practices, farmer awareness, and supportive government policies, will be essential for strengthening the sustainability and competitiveness of the dairy and livestock sectors. Such technological advancements will play a crucial role in realizing the vision of *Viksit Bharat* 2047 by ensuring food security, rural prosperity, and sustainable agricultural development.

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