

Innovations in Veterinary Vaccines and Immunization

Mahanthesh M. T.¹, Ramesh B. K.², Sumathi B. R.³ and Udharwar Sanjaykumar Vithalrao⁴

¹Associate Professor and Head, Dept. of Animal Science and Fisheries, College of Agriculture, Gangavathi, Koppal District, Karnataka - 583227

²Professor and Head, Dept. of Animal Science and Fisheries, College of Agriculture, Hagari, Ballari District, Karnataka

³Associate Professor, Head, Quality Control Section, IAH and VB, Hebbal, Bangalore - 560024

⁴Subject Matter Specialist (Animal Science), ICAR-Krishi Vigyan Kendra, North Goa, ICAR-CCARI, Goa

*Corresponding Author Email: drmahanteshmt@uasraichur.edu.in

Abstract

Veterinary vaccination has moved far beyond the traditional choice between live-attenuated and inactivated products. Rapid advances in molecular biology, genomics, immunology, biomaterials and digital disease surveillance are reshaping how vaccines are designed, produced, delivered and monitored. Recombinant subunit vaccines, viral vectors, DNA- and RNA-based platforms, marker or DIVA vaccines, virus-like particles, improved adjuvants and nanoparticle delivery systems can make immunization more precise while reducing some of the safety and manufacturing limitations of conventional approaches. At the same time, practical innovation is focused on thermostability, needle-free and mucosal delivery, multivalent formulations, rapid platform adaptation and better matching of vaccine schedules to species, age, production system and disease risk. These developments are especially important in livestock and poultry, where a successful vaccine must work not only in an individual animal but across large populations under variable field conditions. Effective vaccination also supports animal welfare, food security, farm profitability and One Health by reducing disease transmission and, in many situations, the need for antimicrobial treatment. Innovation cannot replace good vaccination practice. Cold-chain maintenance, correct handling, quality assurance, biosecurity, surveillance, booster timing and post-vaccination monitoring remain essential. This article explains the major emerging technologies in veterinary vaccines, their practical advantages, current limitations and the direction in which animal immunization is likely to evolve.

Keywords: Veterinary vaccines, Immunization, Recombinant vaccines, DIVA, Nucleic-acid vaccines, Adjuvants, One Health

How to Cite this article: Mahanthesh, M. T., Ramesh, B. K., Sumathi, B. R., & Udharwar, S. V. (2026). Innovations in Veterinary Vaccines and Immunization. *Future Agriculture e-magazine*, September 2026, Issue 3, pp. 191-197.

Introduction

Vaccines are among the most useful preventive tools in veterinary medicine because they prepare the immune system before natural exposure to a pathogen. In livestock, poultry, companion animals and aquaculture, vaccination can reduce clinical disease, mortality, production losses and pathogen circulation. The benefit extends beyond the vaccinated animal: healthier herds and flocks support food production, animal welfare and the economic stability of farmers. Vaccination can also contribute to public health when it is

used against zoonotic infections or when disease prevention reduces the need for antimicrobial treatment.

The basic principle has remained constant, but the technology has changed considerably. Conventional veterinary vaccines generally use a whole organism that has been weakened or inactivated. These products have controlled many important diseases and remain indispensable. Yet whole-pathogen vaccines may have limitations related to safety, duration of immunity, antigenic matching, manufacturing, cold-chain dependence or the

difficulty of distinguishing an infected animal from a vaccinated one. Modern vaccine science therefore aims to deliver only the immune information that is needed, in a form that is safer, more stable, easier to update and better suited to field use.

Veterinary medicine is particularly demanding because there is no single 'animal patient'. Cattle, buffaloes, sheep, goats, pigs, poultry, horses, dogs, cats, fish and wildlife differ in their immune responses, management conditions and economic constraints. A vaccine that performs well in controlled laboratory conditions must still be practical when thousands of animals are vaccinated on farms. Innovation is therefore not only about creating a new antigen. It also includes adjuvants, delivery devices, thermostability, diagnostics, surveillance and vaccination strategies.

From Conventional Vaccines to Precision Platforms

Live-attenuated vaccines contain organisms that can replicate to a limited extent without producing the full disease in a healthy target animal. They often generate strong and durable immunity because they resemble natural infection, but careful attenuation, storage and safety assessment are essential. Inactivated vaccines cannot replicate and are generally considered safer in many situations, although they often need adjuvants, larger antigen quantities and booster doses. Toxoids and bacterins remain useful against several bacterial diseases.

Newer vaccine platforms separate the protective antigen from the rest of the pathogen. This reduces unnecessary biological material and gives developers greater control over what the immune system sees. The approach can also simplify updating when a pathogen changes. In practical terms, modern vaccine design is moving from 'grow the pathogen and modify it' toward 'identify the protective target and engineer the best way to present it'. Genomics, structural biology and bioinformatics now help identify conserved proteins and immune epitopes, while recombinant expression systems make it possible to manufacture those targets without producing large quantities of the disease-causing organism.

Recombinant Subunit and Virus-Like Particle Vaccines

Recombinant subunit vaccines contain selected proteins or antigenic components produced through engineered expression systems. Because the vaccine does not contain a complete infectious pathogen, the safety profile can be attractive, especially where reversion to virulence is a concern. The challenge is that purified proteins may not stimulate immunity strongly enough on their own. Their success therefore depends on antigen selection, formulation and an appropriate adjuvant.

Virus-like particles (VLPs) represent another useful concept. They resemble the outer architecture of a virus but lack the genetic material needed for replication. Their repetitive surface structure can present antigens to the immune system in a highly organized way. VLPs and self-assembling protein nanoparticles are being explored for multiple veterinary pathogens because they combine a virus-like appearance with a non-replicating design. Such platforms can also be engineered to display more than one antigen, opening possibilities for multivalent vaccination.

For farmers and field veterinarians, the value of subunit technology is not simply its molecular sophistication. It may support safer production, consistent batch quality and compatibility with marker-vaccine strategies. The major practical question is whether the product can generate sufficiently strong and long-lasting immunity at a cost suitable for large animal populations.

Viral-Vector Vaccines

Viral vectors use a modified carrier virus to deliver genes encoding protective antigens from another pathogen. The vector enters host cells and produces the target antigen, allowing the immune system to encounter it in a way that can stimulate both antibody and cell-mediated responses. Veterinary research has used several vector families, including poxviruses, adenoviruses and herpesviruses, depending on the target species and disease.

One advantage of vector platforms is that the same delivery backbone can potentially be adapted by replacing or adding the gene that

encodes the desired antigen. This makes the technology attractive when rapid redesign is needed. Vectors can also be designed to express multiple antigens. However, pre-existing immunity to the carrier vector, manufacturing complexity, genetic stability and regulatory evaluation must be considered. A vector that works well in one species may not be suitable in another, and the route of administration can strongly influence immune performance.

DNA, RNA and Rapid-Response Vaccine Platforms

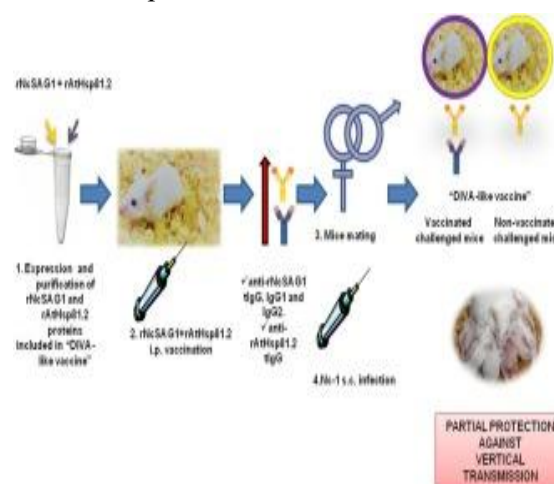
Nucleic-acid vaccines provide genetic instructions rather than a pre-made antigen. DNA vaccines generally use plasmid DNA that enters cells and directs production of the target protein. Veterinary medicine has been an important testing ground for DNA vaccination, and the platform has demonstrated that genetic immunization can be practical in animals. DNA can be relatively stable and straightforward to redesign, but delivery into cells and the strength of the immune response are major determinants of performance.

RNA-based approaches shorten the pathway from genetic sequence to antigen expression. Messenger RNA and self-amplifying or replicon RNA technologies are being investigated because new constructs can be designed rapidly after the sequence of an emerging pathogen is known. Lipid and other nanoparticle systems can protect RNA and improve entry into cells. In veterinary medicine, RNA technologies are especially interesting for quickly changing pathogens and for flexible manufacturing, although large-scale cost, storage, delivery and species-specific optimization remain important challenges.

The greatest promise of nucleic-acid platforms may be their speed. During an outbreak, conventional vaccine development can be slowed by the need to isolate and grow a pathogen at scale. Sequence-based platforms can begin with genetic information. This does not remove the need for safety, potency and field trials, but it can compress early development and make strain updates more efficient.

Marker Vaccines and the DIVA Principle

DIVA means differentiation of infected from vaccinated animals. In a DIVA strategy, the vaccine is designed so that vaccinated animals lack an antigenic marker that would be present after natural infection, or they develop a distinguishable diagnostic profile. A companion laboratory test can then separate infection-induced responses from vaccine-induced responses.



This is important in disease-control and eradication programmes. When a conventional vaccine produces antibodies that look identical to those produced by infection, serological surveillance becomes difficult. Marker vaccines allow vaccination to continue while surveillance identifies animals or herds exposed to field virus. DIVA approaches have therefore become an important objective in vaccines for diseases where proof of infection status affects movement, trade or eradication planning.

DIVA is not a property of the vaccine alone. It is a coordinated system involving vaccine design, a validated companion diagnostic test, appropriate sampling and interpretation. The value of marker vaccination is greatest when laboratory capacity and surveillance are strong enough to use the additional information.

Modern Adjuvants and Nanoparticle Delivery

Many purified or inactivated vaccines require an adjuvant to strengthen and shape the immune response. Traditional adjuvants remain useful, but current research is increasingly focused on formulations that can target antigen-

presenting cells, release antigen gradually or stimulate defined innate immune pathways. Emulsions, saponin-based systems, polymers, liposomes and pattern-recognition receptor agonists are among the approaches used or investigated in veterinary immunology.

Nanoparticles add another layer of control. Polymeric particles, lipid nanoparticles, chitosan systems and self-assembling proteins can protect antigens from degradation and influence where they are delivered. They may increase uptake by antigen-presenting cells, improve the duration of antigen exposure and support mucosal vaccination. This is particularly attractive for oral, intranasal or spray vaccines, where the antigen must survive biological barriers before reaching immune tissues.

The goal is not simply to make immunity 'stronger'. The correct immune response depends on the pathogen. Some diseases are controlled mainly by neutralizing antibodies, whereas others require strong T-cell or mucosal responses. Rational adjuvant selection therefore aims to produce the right type of immunity with acceptable local reactions, residue considerations and manufacturing cost.

Needle-Free, Mucosal and Mass-Application Vaccination

Injection is effective, but it is labour-intensive and may be stressful when very large animal populations are involved. Poultry vaccination already demonstrates the advantages of mass application through drinking water, spray, eye drop or in-ovo systems where appropriate. Similar interest exists in oral and intranasal vaccines for other species because respiratory and gastrointestinal pathogens first encounter the host at mucosal surfaces.

Mucosal vaccination can stimulate local IgA and tissue immune responses in addition to systemic immunity. The difficulty is protecting the vaccine antigen from enzymes, pH changes and physical loss. Encapsulation and bioadhesive delivery systems are being developed to improve antigen stability and contact time. Needle-free jet injectors, patches and other delivery devices may also reduce

needle-associated injuries, cross-contamination and labour requirements in selected settings.

A practical veterinary innovation succeeds only when it fits routine farm work. A theoretically excellent vaccine that requires complicated handling or individual restraint may be less useful than a slightly less sophisticated product that can be delivered reliably to a whole flock. Therefore, ease of administration is increasingly considered during vaccine development rather than after the product is finished.

Thermostability and Cold-Chain Innovation

Vaccine potency depends on correct storage and handling. Heat exposure, repeated warming, freezing of freeze-sensitive products and poor reconstitution practices can reduce effectiveness even when the vaccine itself is scientifically sound. FAO field guidance continues to emphasize cold-chain maintenance and correct administration as central elements of livestock vaccination campaigns.

Thermostable formulations can reduce this vulnerability. Lyophilization, stabilizing excipients, improved vials and formulation technologies are being used to extend vaccine stability. The long-term objective is not necessarily to eliminate the cold chain for every product, but to make vaccines more tolerant of real field conditions. This is especially important in remote livestock areas where electricity, transport and refrigeration may be unreliable.

Digital temperature loggers and vaccine-vial monitoring can complement formulation improvements by showing whether a shipment has remained within the required range. Thus, innovation in immunization includes logistics technology as much as molecular vaccine design.

Multivalent Vaccines and Smarter Immunization Schedules

Farm animals are often exposed to several pathogens within the same production cycle. Combination or multivalent vaccines can reduce handling, labour and the number of injections. The challenge is to ensure that one antigen does not interfere with another and that

the adjuvant and dose are appropriate for all components. Modern formulation science and better immune monitoring are helping developers design combinations more rationally.

Vaccination schedules are also becoming more risk-based. Maternal antibodies, age, pregnancy, nutritional status, previous vaccination, stress, local disease prevalence and the expected time of exposure all influence protection. A fixed calendar may be convenient, but the best schedule is one that matches the biology of the disease and the management system. Serological monitoring, outbreak data and herd-health records can help determine whether primary vaccination and boosters are producing the expected population immunity.

Digital livestock records can strengthen this process by documenting product, batch, date, dose, animal or flock identification and the next due date. When linked with disease surveillance, such records can help identify gaps in coverage and support rapid response during outbreaks.

Practical Relevance Across Animal Sectors

In cattle and buffaloes, innovation is directed toward vaccines that provide durable herd immunity, support large national or regional control programmes and remain practical in extensive production systems. For diseases in which surveillance and trade status are important, marker vaccines and companion diagnostics are particularly valuable. In sheep and goats, low-cost mass vaccination, thermostability and long protection are essential because animals may be managed in mobile or remote systems.

Poultry presents a different challenge: very large populations, short production cycles and the need for rapid mass administration. Spray, drinking-water, in-ovo and vectored technologies can reduce individual handling. Swine production benefits from flexible vaccination platforms that can respond to rapidly evolving respiratory and enteric pathogens, while herd-level monitoring helps determine whether vaccination is controlling clinical disease and transmission.

Companion-animal vaccination is increasingly individualized. Age, lifestyle, travel, geographic risk and previous vaccination can influence the schedule. In wildlife, oral-bait vaccination can be an important method when capture and injection are impractical. Aquaculture similarly requires specialized delivery such as immersion, oral administration or injection depending on species, size and disease. These examples show why veterinary vaccine innovation must be species-specific and management-aware.

A Snapshot of Major Innovations

Table 1. Major technology trends in veterinary vaccines and immunization.

Innovation	Practical significance
Recombinant subunit / VLP	Uses selected antigens or virus-like structures; improves antigen specificity and avoids a complete infectious agent.
Viral-vector vaccines	A modified carrier expresses the target antigen and can stimulate both antibody and cell-mediated responses.
DNA / RNA platforms	Genetic instructions enable rapid redesign and are useful when emerging strains require faster platform adaptation.
DIVA / marker vaccines	Vaccination and companion diagnostics can distinguish vaccinated animals from naturally infected animals.
Advanced adjuvants / nanoparticles	Improve antigen delivery, uptake and the type or duration of immune response.
Thermostable formulations	Reduce vulnerability to storage and transport problems, especially in remote vaccination programmes.
Mucosal / mass delivery	Oral, intranasal, spray or water routes reduce individual handling and may stimulate local immunity.

Challenges That Still Limit Vaccine Performance

A modern platform cannot compensate for poor vaccination practice. Vaccine failure may occur because the wrong product or strain is selected, the cold chain is broken, the dose is incorrect, animals are already incubating disease, boosters are missed or maternal antibodies interfere with early immunization. Malnutrition, parasitism, severe stress and concurrent infection may also reduce the immune response. For this reason, vaccination must be integrated with nutrition, hygiene, biosecurity and disease surveillance.

Pathogen diversity remains another challenge. RNA viruses can evolve quickly, and antigenic differences between field strains and vaccine strains may reduce protection. Genomic surveillance can help detect such changes, but updating a vaccine still requires

manufacturing and regulatory steps. Some pathogens have complex immune-evasion mechanisms or do not induce strong natural protective immunity, making vaccine development intrinsically difficult.

Economics also matters. Food-animal vaccines must often be produced at low cost for very large populations. Sophisticated platforms may be scientifically effective but difficult to deploy if the price per dose, delivery device or storage requirement is too high. Regulatory systems must balance rapid access with evidence for purity, safety, potency and consistency. WOA standards and procurement guidance emphasize that vaccine quality, not price alone, is critical for effective programmes.

Public confidence and farmer participation are essential. Coverage below the level required for herd or flock protection can leave susceptible pockets where disease continues to circulate. Clear communication about expected protection, adverse-event reporting and booster schedules is therefore part of vaccination technology in the broadest sense.

Table 2. Operational factors that influence vaccination success.

Factor	Good practice
Cold-chain integrity	Maintain validated storage and transport conditions and monitor temperature where required.
Timing and animal status	Consider age, maternal antibodies, pregnancy, stress, disease status and product-specific schedules.
Administration technique	Use the labelled dose and route with clean and correctly maintained equipment.
Coverage and boosters	Complete primary courses and boosters so susceptible gaps do not persist in the herd or flock.
Records and surveillance	Record product, batch, date, dose and animal/flock identity and review disease occurrence after vaccination.

The Future: From Vaccine Products to Vaccination Systems

The next phase of veterinary immunization will combine several technologies rather than depend on a single breakthrough. Genomic sequencing will identify emerging strains; computational tools will help select antigens; modular recombinant or nucleic-acid platforms will accelerate design; advanced adjuvants will shape immunity; and digital systems will track distribution, coverage and post-vaccination performance. The result will be a more connected vaccination system.

Target Product Profiles are also gaining importance in international veterinary vaccine planning. Instead of beginning with a laboratory platform and only later considering field use, developers define the characteristics needed for a particular epidemiological setting: target species, route, onset and duration of immunity, storage, DIVA compatibility, number of doses and affordability. This helps align research with real disease-control needs.

One Health will remain a major driver. Animal vaccines can reduce the burden of zoonotic disease, lower economic losses and reduce situations in which antimicrobials are used to manage preventable bacterial infections. The strongest future programmes will therefore treat vaccination as part of integrated animal health, combining immunization with diagnostics, biosecurity, surveillance, vector control and responsible antimicrobial use.

Conclusion

Veterinary vaccines are moving from broad, conventional preparations toward increasingly precise and adaptable platforms. Recombinant antigens, viral vectors, DNA and RNA systems, DIVA vaccines, advanced adjuvants, nanoparticles, mucosal delivery and thermostable formulations are expanding the options available to animal-health professionals. Their practical value lies in safer production, rapid updating, better immune targeting, easier mass application and stronger disease surveillance.

The best vaccine is still only one component of a successful immunization programme. Correct storage, handling, timing, species-specific schedules, booster compliance, biosecurity and monitoring determine whether laboratory potential becomes field protection. Future progress will come from combining molecular innovation with reliable delivery systems and strong veterinary services. When these elements work together, vaccination can protect animal health, support farm productivity, improve food security and contribute to the wider One Health goal of protecting animals, people and their shared environment.

References

- Ferrari, G., & Mariano, V. (2022). Guidelines for livestock vaccination campaigns. Food and Agriculture Organization of the United Nations (FAO).
- Jogi, H. R., Smaraki, N., & Rajak, K. K. (2024). Revolutionizing veterinary health with viral vector-based vaccines. *Indian Journal of Microbiology*, 64(3), 867–878. <https://doi.org/10.1007/s12088-024-01341-3>
- Nooraei, S., Lotfabadi, A. S., Akbarzadehmoallemkolaei, M., & Rezaei, N. (2023). Immunogenicity of different types of adjuvants and nano-adjuvants in veterinary vaccines: A comprehensive review. *Vaccines*, 11(2), 453. <https://doi.org/10.3390/vaccines11020453>
- World Organisation for Animal Health (WOAH). (2024). *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* (13th ed.).
- World Organisation for Animal Health (WOAH). (2024). *Practical Guidelines for National Procurement of Veterinary Vaccines*.
- World Organisation for Animal Health (WOAH). (2025). *Veterinary Vaccines and Vaccination: From Science to Action - Reflections for Change* (92nd General Session Technical Item).
- World Organisation for Animal Health (WOAH). (2026). *Guidelines for African swine fever vaccines: Field evaluation and post-vaccination monitoring*.
- World Organisation for Animal Health (WOAH). (2026). *Ad hoc Group report on development of a Target Product Profile template for veterinary vaccines*.