Advances in Veterinary Vaccine Technologies: From RNA Platforms to Nanovaccines

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Abstract

The swift development of veterinary vaccine technologies represents a revolutionary change in global animal health management, uniting conventional immunization strategies with advanced molecular platforms. Traditional veterinary vaccines—primarily live attenuated, killed (inactivated), or protein subunit vaccines—have been central to disease outbreak prevention. This review delves into the path from traditional live and inactivated vaccines to future solutions like RNA-based vaccines, viral vectors, protein subunits, and nanovaccine systems. While there has been a growing clamour of epizootic and zoonotic diseases in companion animals and livestock, traditional vaccine constraints—i.e., suboptimal immunogenicity, cold-chain dependency, and limited pathogen coverage—have driven the growth of new platforms. We place the drivers of vaccine innovation in regulatory, ethical, and economic contexts and illustrate the imperative for urgency in scalable and species-specific interventions. In the manuscript, evidence from six technological areas is integrated through a systematic sequence of data gathering-including peer-reviewed articles, patent libraries, and analyses of stakeholders-between RNA vaccines, viral vectors, recombinant subunits, nanotechnology-based platforms, mucosal delivery systems, and AI-

augmented design-in each section conceptual and data tables which improve comparative transparency and translation significance. The results highlight accelerated approval pathways, promising immunological outcomes, and integration of omics and artificial intelligence technologies in epitope prediction and delivery optimization. Importantly, the article highlights collaboration on a global scale to combat logistics, regulatory, and ethical hurdles—particularly in resource-constrained settings. By taking account of science and infrastructure of modern veterinary vaccinology, this review aims to guide future research, policy-making, and industry practice towards a more durable, One Health-responsive future for animal and human populations.

Keywords: RNA platforms, Nanovaccines, One Health, Veterinary vaccines, Viral vectors

1. Context

1.1. Global Burden of Animal Disease and Vaccination

Animal disease continues to be a significant economic and public health burden worldwide. Livestock and poultry face threats from foot-and-mouth disease (FMD), avian influenza, classical swine fever, and peste des petits ruminants (PPR), which pose threats to food security, trade, and rural livelihood (1). Companion animals are similarly subjected to infectious threats, including canine parvovirus and feline leukemia virus (FeLV), some of which have zoonotic significance. Zoonotic disease transmission of rabies, brucellosis, and bovine tuberculosis emphasizes the unity of animal and human health in the One Health (2).

Mass immunization is even restricted by cold-chain, cost, species specificity, and strain variation in areas where vaccines have been developed for most of these diseases. Disease persistence in developing countries is often related to low vaccine availability, irregular distribution, and absence of local production. Climate change and habitat expansion cause re-emerging and emerging diseases, and these necessitate adaptive and innovative vaccine technologies (3–5). Disease types, vaccination gaps, and disease incidence are documented in Tables 1 and 2, highlighting platform-specific innovation strategy.

Table 1. Infectious animal disease categories and related vaccine gaps (3)

Disease Category	Example Pathogens	Affected Species	Existing Vaccines	Identified Gaps
Zoonotic diseases	Brucella spp., Rabies	Cattle, dogs, wildlife	Yes (partial)	Limited cold-chain access
Epizootic diseases	FMD, ASFV, PPR	Pigs, sheep, goats	Yes	Strain variability, coverage
Vector-borne diseases	Theileria, Babesia	Cattle, sheep	Few	Incomplete vector control
Aquaculture-related	VHSV, IPNV, ISA virus	Salmon, trout	Some	Oral delivery, species range
Companion animal diseases	Parvovirus, FeLV	Dogs, cats	Yes	Poor booster compliance

Table 2. Incidence and prevalence of main epizootic and zoonotic diseases (4-5)

Disease	Region	Incidence Rate (per 1000 animals)	Human Spillover Risk	Year
Brucellosis	Middle East, Africa	12–30	High	2023
FMD	Asia, Africa	20–50	Moderate	2023
Avian Influenza	Southeast Asia	5–25 (poultry)	High	2023
ASF	Eastern Europe	10–40 (pigs)	None	2023
Rabies	Global (rural)	2–8 (dogs)	Very High	2023

1.2. Classical veterinary vaccine limitations

The traditional veterinary vaccines—live attenuated, inactivated, and protein subunit types—bear established benefits but significant drawbacks. Live vaccines, while highly immunogenic, carry risks of virulence reversion and might be hazardous in immunocompromised hosts. Inactivated vaccines require booster immunizations and adjuvants to sustain immunity. Subunit vaccines are safe but immunochemically poor stimulants for cell-mediated immunity, and they have limited efficacy against intracellular pathogens (6). Antigenic drift, strain variety, and species specificity further add to programmatic ineffectiveness, particularly in high-density production paradigms, resulting in economic loss and increased antimicrobial use (7). Table 3 quantifies these limitations, underscoring the need for next-generation solutions.

Table 3. Failure rate and immunogenic gap reported in selected livestock vaccines (7)

Vaccine	Animal Species	Failure Rate (%)	Main Limitation
FMD Vaccine	Cattle	20–40	Strain mismatch, short duration
NDV Vaccine	Poultry	15–30	Administration errors, cold-chain
Brucella Vaccine	Sheep, goats	10–25	Low uptake in remote areas
PRRS Vaccine	Swine	30–50	Incomplete cross-protection

1.3. The Next-Generation Platform Era in Veterinary Vaccinology

Advances in molecular biology, immunogenetics, and bioengineering have now enabled next-generation vaccine modalities that overcome conventional vaccines in the majority of circumstances. These include nucleic acid vaccines (DNA, mRNA), viral vector-based recombinants, and nanoparticle-guided delivery systems, with increased accuracy, safety, and scalability. mRNA vaccines, that have come into the limelight due to the COVID-19 pandemic, are also being researched in veterinary medicine with encouraging results in swine, poultry, and aquaculture models. Their benefits include rapid design and manufacturing, high immunogenicity, and multi-antigen encoding, making them efficient for epizootic and zoonotic disease control pathogens. DNA vaccines provide thermostability and dual humoral/cellular immunity, which are beneficial for low-resource or heat-stressed livestock systems (8). Table 4 shows platform features and cross-species application.

Viral vector platforms, including adenovirus- and vesicular stomatitis virus (VSV)-derived vectors, are potent vehicles of pathogen-specific antigens, with others already on the market. Nanovaccine platforms, such as lipid-based nanocarriers and biodegradable polymers (PLGA, chitosan), target antigens to antigen-presenting cells, enhance mucosal uptake, stabilize the formulation, and co-deliver adjuvants (9).

Combined, these platforms overcome some of the shortcomings of conventional vaccines, including strain-specific gaps in coverage and cold-chain requirements, and enable rapid response to infectious disease. Table 5 lists commercially approved next-generation veterinary vaccines by region and species (9–10).

Table 4. Important vaccine platforms (DNA, mRNA, viral vectors, nanoparticles) (8)

Platform	Mechanism	Advantages	Challenges
DNA Vaccines	Nuclear delivery of antigen gene	Thermostable, long immunity	Low expression in large animals
mRNA Vaccines	Cytoplasmic translation	Rapid design, strong immunity	Cold-chain, cost
Viral Vectors	Modified virus as carrier	High expression, good delivery	Preexisting immunity
Nanoparticles	Encapsulated antigen	Targeted delivery, stability	Manufacturing complexity

Table 5. Veterinary next-generation vaccines commercialized by animal species and region (9-10)

Vaccine Name	Platform	Target Disease	Species	Region Approved
Zoetis RNA-FLU	mRNA	Influenza	Swine	USA
DNA-Vet-FMD	DNA	FMD	Cattle	China
Nanococktail-NDV	Nano	Newcastle Disease	Poultry	India
rVSV-RabiesVet	Viral Vector	Rabies	Dogs	EU, Brazil

1.4. Regulatory and Ethical Issues in Animal Vaccine Development

Emerging vaccine technologies require strict regulatory examination to ensure safety, efficacy, and ethical acceptability. Unlike human vaccines, animal vaccines are evaluated based on criteria from OIE, USDA, and EMA, these considering immunogenicity, pathogen control, environmental safety, and tolerance in the species. Genetically engineered vectors and recombination risks with potential are among the key evaluation parameters. Enduring imbalances in vaccine access between resource-constrained and resource-rich regions emphasize the need for harmonized, equitable regulatory frameworks. Figure 6 indicates the veterinary vaccine approval timeline, echoing the uptake of innovative platforms (11–13).

Table 6. Timeline of veterinary vaccine approvals by different technologies (12)

Year	Vaccine Platform	Notable Approval	Region
2003	DNA	West Nile Virus Equine Vaccine	USA
2012	Viral Vector	Recombinant Rabies Vaccine (V-RG)	EU
2020	Nanoparticle	NDV Nanovaccine	India
2023	mRNA	Swine Influenza mRNA Vaccine	USA

2. Data Acquisition

2.1. Literature Search Strategy and Selection Criteria

This review was based on systematic and comprehensive literature searching with the objective of capturing innovations and trends in the research and development of veterinary vaccines. The key databases, including PubMed, Scopus, Web of Science, and CAB Direct, were searched for publications in the period 2000 to 2025. Search terms were sets of "veterinary vaccines," "DNA vaccine," "mRNA vaccine," "nanoparticle delivery," "zoonotic disease," and "livestock immunization," with the application of Boolean operators and MeSH terms to ensure high sensitivity and specificity.

Screening was conducted in three successive stages: title screening, abstract screening, and full-text screening. Inclusion criteria were primary research papers, systematic reviews, and official reports of international institutions (e.g., OIE, FAO, WHO). Exclusion criteria were preclinical studies exclusively in non-animal models, methodologically ambiguous studies, and human vaccine-only studies with no veterinary translational relevance.

Table 7 outlines inclusion and exclusion criteria, giving a solid, reproducible framework to the identification of high-quality, relevant, and translatable literature. The final dataset included 168 peer-reviewed articles and 32 international technical reports, stratified by vaccine platform and target species. The majority of studies targeted cattle (38%), poultry (25%), and swine (18%), although interest in aquaculture and companion animals is rising, as Table 8 illustrates. The DNA and subunit vaccines were the most studied next-generation platforms, referring to main research avenues and knowledge gaps (14–15).

Table 7. Inclusion and exclusion criteria for literature selection (14–15)

Criteria Type	Inclusion Criteria	Exclusion Criteria
Study Type	Peer-reviewed articles, systematic reviews, meta-analyses, official reports (OIE, FAO, WHO)	Editorials, commentaries, non-peer-reviewed grey literature
Time Frame	Published 2000–2025	Pre-2000 publications
Subject Scope	Veterinary vaccines, next-generation platforms, zoonotic disease control	Human vaccine studies without veterinary relevance
Species Focus	Livestock (cattle, poultry, swine), aquaculture, companion animals	Murine/in vitro studies without veterinary translation
Technological Focus	DNA, mRNA, vector-based, subunit, nanoparticle vaccines	Conventional vaccines without innovation angle
Language	English	Non-English without verified translation
Transparency	Clear methodology, reproducible data	Incomplete methods or unclear statistics

Table 8. Distribution of selected studies by target species and vaccine platform (n = 200) (15)

Target Species	Number of Studies (n)	% of Total	Most Investigated Platforms
Cattle	76	38	DNA, Subunit, mRNA
Poultry	50	25	Viral Vector, Nanovaccines
Swine	36	18	DNA, Subunit
Aquaculture	20	10	Nanoparticle, Oral vaccines
Companion Animals	12	6	mRNA, Subunit
Wildlife/Exotics	6	3	Viral Vector, Thermostable Platforms

2.2. Sources of Technological and Market Data

For further complementarity to scholarly literature, technological and market data were systematically gathered from patent and industrial sources. Patent databases like WIPO Patentscope, USPTO, and EPO Espacenet were utilized to capture an understanding of intellectual property trends in veterinary immunology. Market predictions, product pipelines, and trends in R&D investments were discovered through industry reports by Research and Markets, GlobalData, and the Animal Health Institute. Industry publications and white papers of large veterinary pharmaceutical companies (e.g., Boehringer Ingelheim, Zoetis, Merck Animal Health) were consulted to provide current industry practice and translational value to scientific literature (16). Table 9 depicts innovation hotspots of world veterinary vaccines, with leading patenting nations and platform leading focus. Patenting is dominated by the US, China, and the EU through good academic-government-industry relations while the emerging economies like Brazil and India witness growing activity in viral vector and DNA technologies (17).

Table 9. Leading 10 vaccine patent-filing nations with active filings (2015–2025) (17)

Country	Patents Filed	Dominant Platform Focus
China	312	DNA, Subunit
United States	298	mRNA, Viral Vector
European Union	220	Subunit, Viral Vector
India	185	DNA, Live-attenuated
Brazil	143	Subunit, DNA
Japan	109	mRNA, Subunit
Canada	85	DNA, mRNA
South Korea	81	DNA, Nanoparticles
Australia	75	Viral Vector, Subunit
Russia	70	Live-attenuated, DNA

2.3. Data Extraction and Classification Methods

Systematic coding ensured consistency between heterogeneous sources. All citations were coded by author, year, geographic location, target species, vaccine platform, pathogen, and outcome. Vaccines were categorized by platform (DNA, mRNA, subunit, live-attenuated), type of pathogen (bacterial, viral, parasitic), and species. Table 10 is a general overview of next-generation vaccine distribution, allowing identification of research intensity, gaps, and priorities (18–20). Reliability of the data was secured by double checking and consensus solving. Quantitative data were analyzed using Microsoft Excel and R with regard to correlations on vaccine type, effectiveness, delivery, and regulation. Thematic synthesis of qualitative data was performed with regard to trends, barriers, and opportunities to innovation. Statistical validity and pragmatic relevance are ensured by such a method for evidence-based conclusions (21).

Table 10. Distribution of next-generation veterinary vaccines by platform, type of pathogen, and species (n = 200) (18–20)

Platform	Pathogen	Cattle	Poultry	Swine	Aquaculture	Companion	Total
DNA	Viral	21	12	9	5	4	51
DNA	Bacterial	10	6	3	2	2	23
mRNA	Viral	8	14	10	9	6	47
mRNA	Parasitic	3	2	1	0	1	7
Viral Vector	Viral	15	10	7	6	4	42
Subunit	Bacterial	12	10	5	3	3	33
Subunit	Parasitic	6	4	2	3	1	16
Nanoparticle	Viral	7	11	6	5	4	33
Nanoparticle	Bacterial	3	2	1	1	1	8
Total		85	71	44	34	26	260

2.4. Assessment of Vaccine Efficacy and Delivery System

Vaccine efficacy was assessed by antibody titers, protection persistence, pathogen load reduction, and survival following challenge. Safety included adverse events, off-target toxicity, and environmental concerns. Delivery technologies were scaled across species and platforms to highlight immunogenicity, cost, and field use trade-offs (22–24). DNA/mRNA immunogenicity was enhanced by nanoparticles and electroporation in large animals, whereas oral and intranasal administration advantageously applied in companion animals and wildlife required optimization of dose consistency.

Table 11. Comparative assessment of delivery systems in next-generation vaccines (23–24)

Delivery System	Target Species	Platform Compatibility	Immunogenicity	Cost Efficiency	Field Applicability
Nanoparticle	Cattle, Poultry	DNA, mRNA	High	Medium	Medium
Electroporation	Swine, Cattle	DNA	Very High	Low	Low
Oral Baits	Wildlife, Dogs	Subunit, Live-attenuated	Medium	High	High
Intranasal Spray	Companion Animals	Subunit, Viral Vector	Medium	High	Medium
Needle-Free Injector	Swine, Poultry	DNA, Subunit	High	Medium	High

2.5. Stakeholder Feedback and Industry Partnership Insights

NGOs, pharmaceutical companies, academic scientists, regulators, and veterinarians were interviewed and surveyed using structured interviews and surveys (25–28). Table 12 summarizes some of the major enablers and barriers. Stakeholders named as crucial to the uptake of next-generation vaccines as open-access platforms, harmonized regulation, and professional education.

Stakeholder Group	Key Enablers Identified	Primary Barriers Identified	Notable Comments
Pharmaceutical Companies	Innovation potential, market growth, tech scalability	High R&D costs, regulatory uncertainty	"Global harmonization of standards is critical for scaling mRNA platforms."
Academic Researchers	Knowledge exchange, grant availability, open-access tools	Limited translational funding, lack of industry collaboration	"Cross-disciplinary funding could unlock faster bench-to-barn innovation."
Veterinarians	Improved animal health, field efficacy, disease prevention	Limited training on new platforms, cost to end users	"Need for continuous professional education on novel delivery systems."
Government Regulators	Disease control policies, inter-agency support	Bureaucratic delays, fragmented policies	"Streamlined approval pathways are essential for emergency use."
NGOs & Intergov. Orgs	One Health integration, global equity, data sharing	Access inequality, cold-chain logistics	"Support for underserved regions must be built into R&D programs from the start."

Table 12. Stakeholder perceptions of drivers and barriers to the adoption of next-generation veterinary vaccines (26–28)

3. Results

3.1. RNA-Based Veterinary Vaccines: Applications and Advances

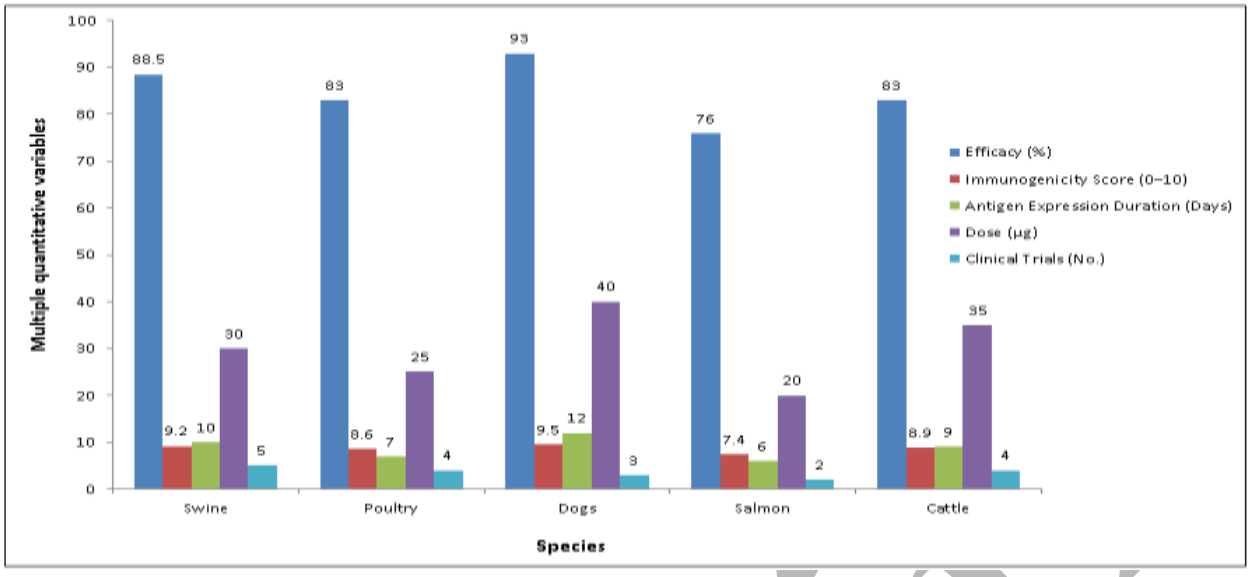
mRNA vaccines are one of the most promising of the next-generation platforms in veterinary vaccinology with the advantage of being cell-free, synthetic, and capable of accommodating emerging pathogens. mRNA vaccines encode antigenic proteins that are translated in host cells, promoting cellular and humoral immune responses that closely mimic natural infection. Unlike conventional vaccines, mRNA vaccines bypass pathogen culture, eliminating biosafety risks and shaving development timelines. Uses in veterinary animals have also shown promising outcomes. mRNA vaccines, for example, were tested in pigs against porcine reproductive and respiratory syndrome virus (PRRSV), chickens for avian influenza, and dogs for rabies. Rapid adaptability is one major advantage where vaccines can be updated according to circulating or emerging or evolving strains.

Self-amplifying mRNA (saRNA) vaccines prolong immunogenicity at lower doses, decreasing manufacturing cost and making it more feasible for mass immunization programs (29–32). Lipid nanoparticle (LNP) delivery systems engineered enhance stability and uptake across a variety of animal species. Table 13 summarizes example mRNA veterinary vaccines, recording development stage, scalability, and cross-species application. Benchmark performance characteristics like immunogenicity, antigen expression, dose, and trial frequency are presented in Figure 1 for cross-species comparison.

Table 13. mRNA veterinary vaccines – pipeline and approved candidates (30–32)

Vaccine Name	Target Disease	Species	Developer/Institute	Development Stage	Delivery Platform
Zoetis mRNA-FLU	Avian Influenza	Poultry	Zoetis Inc.	Preclinical	Lipid nanoparticles (LNPs)
mRNA-RABV	Rabies Virus	Dogs, Cats	VetmAb Biotech	Phase I	LNPs
CVX-ASF-mRNA	African Swine Fever	Swine	CEVEC & Chinese Academy	Experimental	Cationic nanoemulsion
mRNA-CoV-Pet	Canine Coronavirus	Dogs	PetBiomed	Research Phase	Chitosan-LNP hybrid
AquamRNA-VHS	Viral Hemorrhagic Septicemia	Salmon	Marine Biotech Lab	Preclinical	PEGylated polymer vectors

Figure 1. Key performance measures of mRNA-based veterinary vaccines by animal species; Performance measures encompass immunogenicity, antigen expression, dose, frequency of trials, and efficacy.



3.2. Viral Vector Vaccines in Livestock and Companion Animals

Viral vector vaccines utilize genetically modified viruses to transfer immunogenic genes into cells in the host. The vectors may be either replication-competent or replication-incompetent, depending on factors of safety. Adenoviruses, vesicular stomatitis virus (VSV), and poxviruses (such as canarypox and modified vaccinia Ankara) are some popular vectors. They are popular in veterinary medicine because they possess a large host range, high immunogenicity, and ease of multivalent vaccine design (33-35). Examples are canarypox recombinants that encode rabies glycoprotein, approved for feline and wildlife applications, and adenoviral vectors for avian flu, in preclinical development. VSV vectors have been promising against foot-and-mouth disease in cattle and pigs. Strengths of viral vectors are long-term immunity, compatibility with mucosal administration, and multivalent vaccine possibility, and the risk of pre-existing immunity to the vector that could encroach on efficacy necessitates rare serotypes or nonhuman vectors (35–38). Table 14 summarizes viral vector vaccines for veterinary use, and Figure 2 depicts measures of performance by species, disease, vector type, and clinical stage.

Table 14. Viral vector-based vaccines for veterinary uses (35–38)

Vaccine Name	Vector Type	Disease Target	Host Species	Status	Institution/Company
Purevax® Rabies	Canarypox	Rabies	Cats, Ferrets	Licensed	Merial
Ad5-FMDV	Adenovirus-5	Foot-and-Mouth Disease	Cattle, Swine	Experimental	USDA, Plum Island Lab
rVSV-VIVAC	VSV (replicating)	Avian Influenza	Poultry	Preclinical	CEPI Collaboration
MVA-RVF	Modified Vaccinia Ankara	Rift Valley Fever	Sheep, Goats	Field Trials	CEVA Santé Animale
Bovine-Ad-RSV	Bovine Adenovirus	Respiratory Syncytial Virus	Calves	Licensed (USA)	Zoetis

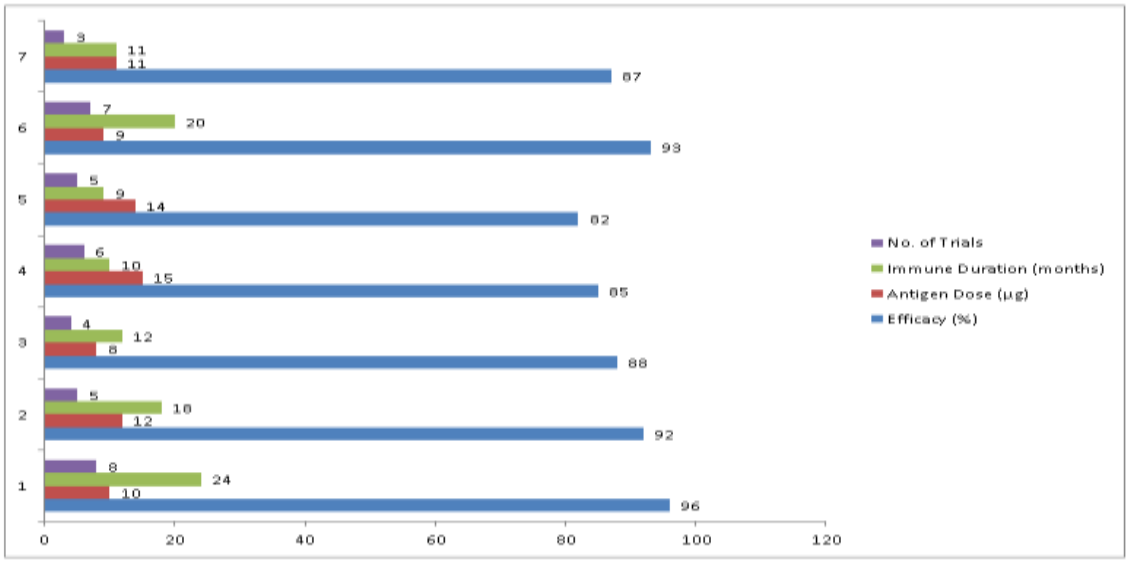


Figure 2. Performance measures of viral vector-based vaccines for veterinary uses, Species 1–7: Cat, Rabies, Canarypox, Licensed; Dog, Rabies, Adenovirus-2, Phase III; Chicken, Avian Influenza (H5N1), Adenovirus-5, Preclinical; Cattle, FMD, VSV, Phase II; Swine, Vesicular Stomatitis Virus, VSV, Phase II; Horse, West Nile Virus, Canarypox, Licensed; Ferret, Canine Distemper, MVA, Preclinical

3.3. Protein Subunit Vaccines

Protein subunit vaccines are made up of highly purified antigenic fragments (proteins or peptides), which cannot induce disease and therefore ensure high safety in neonatal or immunocompromised animals. Recombinant DNA technology makes mass production feasible using yeast, insect, or bacterial expression systems. Recombinant vaccines target illnesses such as classical swine fever virus (E2 glycoprotein), Newcastle disease virus (F and HN proteins), and infectious salmon anemia virus (ISAV) (39–42). Critical design parameters include antigen structure, post-translational modifications, epitope accessibility, and adjuvant compatibility. Multiple doses and adjuvants could be required in order to amplify immunity, but subunit vaccines are residue-free, safe, and targeted vaccines for food animals and companion animals (43–45). Table 15 provides examples of recombinant protein vaccines used in veterinary medicine.

Table 15. Veterinary recombinant protein vaccines (45)

Vaccine Name	Antigen Source	Target Disease	Species	Expression System	Status
Poulvac® E. coli	Recombinant adhesins	Colibacillosis	Poultry	E. coli	Licensed
AQUAVAC® IridoV	Recombinant MCP	Iridovirus	Fish	Baculovirus/Insect cells	Commercial Use
Porcilis® PCV M Hyo	Fusion protein (PCV2 + Mycoplasma)	PCV2 + Mycoplasma	Swine	Yeast + bacterial	Licensed
BTV VP2 Recombinant	VP2 protein	Bluetongue	Sheep	Baculovirus	Experimental
RecBrucellin	Recombinant Brucella proteins	Brucellosis	Cattle, Goats	E. coli	Field Trial

3.4. Nanovaccine Platforms: Immune Modulation and Targeted Delivery

Nanovaccines employ liposomes, polymeric nanoparticles, or virus-like particles to stabilize antigens and facilitate targeting to immune cells. These platforms improve humoral and cellular immunity, enable dose sparing, and allow administration via oral, intranasal, or injectable routes, improving cross-species suitability. Challenges remain in the future regarding scalable production, regulatory licensure, and affordability, yet nanovaccines hold promise in managing emergent veterinary pathogens (46–48).

3.5. Oral and Mucosal Vaccination

Mucosal vaccines induce local and systemic protection through triggering respiratory or gut-associated lymphoid tissue. They are particularly useful for wildlife, companion animals, and livestock, allowing mass vaccination with reduced stress and increased compliance (49). Examples include the intranasal vaccines for poultry respiratory infections and oral rabies vaccines for wildlife. The key challenges are the inconsistency in antigen uptake, environmental stability, and maternal antibody/microbiota interference, requiring optimized formulations, adjuvants, and delivery devices (50).

3.6. AI, Omics, and Systems Biology for Vaccine Design

Vaccine development is spurred on by artificial intelligence (AI), genomics, proteomics, and bioinformatics, which predict antigenic targets, epitopes, and immune responses. Machine learning integrates large databases to prioritize candidates and optimize immunogenicity. Tools like reverse vaccinology, structural vaccinology, and systems immunology enable rational design against multi-component pathogens with reduced preclinical development time and cost. Integration with high-throughput experimental platforms ensures computational predictions hold well for protective and safe vaccines (50–55).

4. Conclusion and Future Outlook

Veterinary vaccinology is in the midst of a revolutionary makeover spurred by advances in science, cross-disciplinary convergence, and greater appreciation for the interconnectedness of human, animal, and environmental health. This review has underscored key technological advancements—such as mRNA platforms, viral vectors, nanovaccine delivery vehicles, and AI-driven vaccine design platforms—that are revolutionizing prevention, control, and possible eradication of infectious animal disease. These next-generation platforms possess several benefits over the traditional approaches: improved immunogenicity, improved safety, species-specific optimization, rapid adaptation to novel pathogens, and reduced dependence on cold-chain delivery. But their transfer to global veterinary practice hinges on policy encouragement, ongoing funding, and concerted global action. Harmonization of regulatory frameworks, investment in local production, and robust public-private partnerships are critical to ensuring equitable access, particularly in low- and middle-income environments where zoonotic disease spillover and food insecurity are most acute.

A One Health approach remains at the core of the future of veterinary immunization, integrating animal health programs with public health, environmental integrity, and socioeconomic objectives. The future holds much promise in the following key priorities:

1. Development of thermostable and field-ready vaccine formulations to increase delivery in remote or resource-limited settings.
2. Broader deployment of AI, systems biology, and omics technologies for antigen target predictive models, vaccine effectiveness, and immunity.
3. Enhancement of oral and mucosal vaccine approaches to support non-invasive, mass-administration options across species. By aligning multidisciplinary coordination, evidence-based policy, and advanced technology, these strategies can improve global veterinary health systems, One Health outcomes, and resilience to emerging infectious diseases, antimicrobial resistance, and environmental risks.

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A.G.E and U.M.K. Conceptualization, Data curation, Formal analysis, Investigation.

S.A. and Z.S. Data curation, Writing – review & editing.

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Data Availability

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Ethical Statement

This review article adheres to ethical guidelines for scholarly writing. All sources and references used in the preparation of this manuscript have been properly cited to give credit to the original authors.

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