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# Vaccine Development for Major Goat Diseases

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**Abstract** This study explores the progress, challenges, and future prospects of vaccine development for major goat diseases, introduces bacterial, viral, and parasitic diseases, as well as corresponding advances in traditional and modern vaccine technologies, including innovative delivery systems such as recombinant, DNA, RNA based vaccines, and nanoparticles. Key challenges such as pathogen diversity, regulatory barriers, and on-site adoption barriers are discussed, and case studies emphasize the successful implementation of vaccination programs, providing insights for effective disease control strategies. Looking ahead, combining genomics, proteomics, and artificial intelligence with vaccine development is expected to accelerate breakthroughs, and global cooperation and policy support are crucial for equitable access to vaccines. Continuous innovation and coordinated efforts are crucial for improving goat health, increasing productivity, and promoting global sustainable animal husbandry.

**Keywords** Goat; Vaccine development; Peste des petits ruminants (PPR); Bacterial diseases; Parasitic diseases

## 1 Introduction

Goat diseases pose significant challenges to the livestock industry, impacting both animal health and economic stability. These diseases, such as tuberculosis, Johne's disease, goatpox, and peste des petits ruminants (PPR), can lead to severe health issues and substantial economic losses due to decreased productivity and increased mortality rates (Bezos et al., 2017; Boshra et al., 2024). The control and prevention of these diseases are crucial for maintaining the health of goat populations and ensuring the sustainability of goat farming, which is a vital source of livelihood for many communities worldwide.

Vaccine development plays a pivotal role in the management and prevention of major goat diseases. Effective vaccines can significantly reduce the incidence and severity of infections, thereby improving animal welfare and productivity. For instance, the development of vaccines like the *Mycobacterium tuberculosis* $SO_2$ vaccine and the indigenous vaccine for Johne's disease has shown promising results in reducing disease severity and improving health outcomes in goats (Singh et al., 2010). Additionally, multivalent vaccines, such as those targeting capripoxvirus and PPR, offer protection against multiple pathogens, enhancing the overall resilience of goat herds against infectious diseases (Byadovskaya et al., 2024; Long et al., 2024).

This study provides a comprehensive overview of the current status of vaccine development for major goat diseases, explores the impact of these diseases on goat health and animal husbandry, emphasizes the importance of vaccines in disease control, and discusses the latest developments and challenges in vaccine research. This review aims to provide information for future research directions and policy decisions to improve the health and productivity of goats by synthesizing the results of various studies.

## 2 Major Diseases Affecting Goats

Goats are susceptible to a variety of diseases that can significantly impact their health and productivity (Xu, 2024). These diseases can be broadly categorized into bacterial, viral, and parasitic diseases, each requiring specific strategies for prevention and control.

### 2.1 Bacterial diseases

One of the major bacterial diseases affecting goats is tuberculosis, caused by *Mycobacterium* species such as *Mycobacterium bovis* and *Mycobacterium caprae*. Vaccination efforts, such as those using the *Mycobacterium tuberculosis* $SO_2$ vaccine, have shown promise in reducing lesion severity and bacterial load in infected goats, suggesting potential for controlling this disease (Bezos et al., 2017). Another significant bacterial disease is Johne's disease, caused by *Mycobacterium avium* subspecies paratuberculosis (Hanafy et al., 2023). The use of indigenous vaccines has been effective in improving the physical condition and reducing mortality and morbidity in infected goats, highlighting the importance of vaccination in managing this disease (Singh et al., 2010; Singh et al., 2013).

### 2.2 Viral diseases

Goats are also affected by several viral diseases, including goatpox and peste des petits ruminants (PPR). Goatpox, caused by the goatpox virus, leads to severe economic losses, and efforts to develop safer vaccines, such as multi-epitope subunit vaccines, are ongoing (Figure 1) (Long et al., 2024). PPR is another critical viral disease, with vaccines like the ARRIAH live attenuated strain showing efficacy in protecting goats against virulent strains (Byadovskaya et al., 2024). Additionally, recombinant adenovirus vaccines expressing PPRV proteins have demonstrated complete protection against pathogenic virus challenges, offering a promising DIVA (Differentiating Infected from Vaccinated Animals) vaccine option (Herbert et al., 2014).

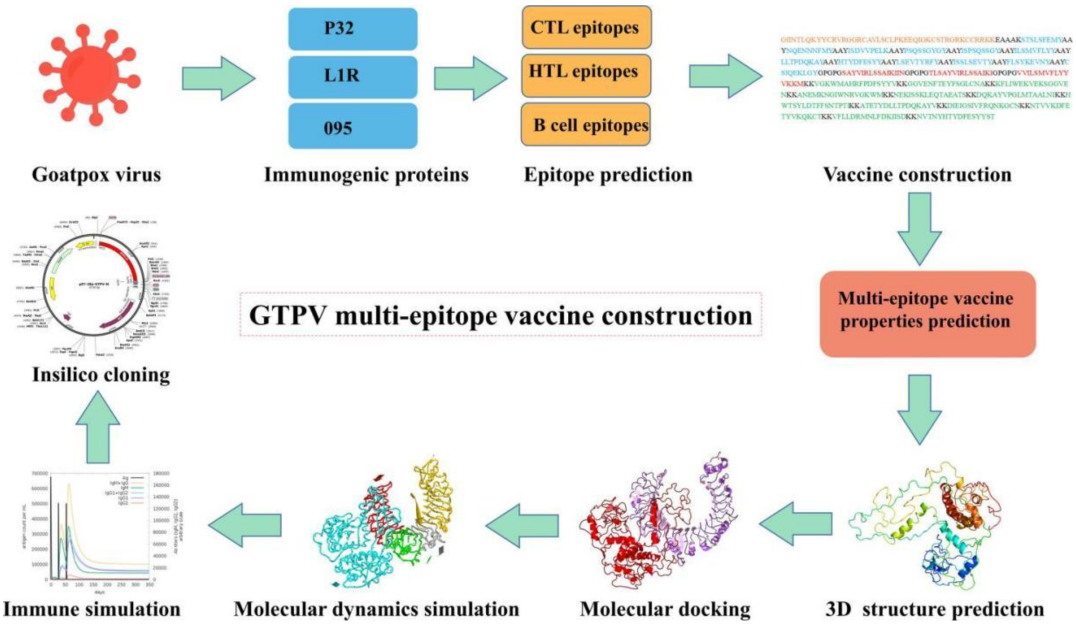

Figure 1 Flow chart for constructing the multi-epitope vaccine (Adopted from Long et al., 2024)

### 2.3 Parasitic diseases

Parasitic diseases, although not explicitly detailed in the provided data, are known to affect goats significantly. Common parasitic infections include those caused by gastrointestinal nematodes, which can lead to reduced productivity and increased mortality. Control measures typically involve the use of anthelmintics and management practices to reduce parasite load and transmission.

## 3 Advances in Vaccine Development for Goats

### 3.1 Traditional vaccine approaches

Traditional vaccine approaches for goats have primarily relied on live attenuated vaccines (Shou and Cai, 2024). These vaccines have been used to control diseases such as goatpox and peste des petits ruminants (PPR). For instance, the ARRIAH live attenuated vaccine has been shown to effectively protect goats from virulent strains of PPR virus, demonstrating its efficacy and safety in experimental settings (Byadovskaya et al., 2024). Similarly, live attenuated vaccines have been used to control sheep and goat pox, although they can sometimes cause mild clinical symptoms in highly stressed animals (Boshra et al., 2015). These traditional vaccines have been crucial in managing goat diseases, but they often come with challenges such as potential side effects and the risk of disease spread.

### 3.2 Modern vaccine technologies

Modern vaccine technologies have introduced innovative approaches such as recombinant and vectored vaccines. For example, a recombinant adenovirus expressing the haemagglutinin of PPRV has been developed as a DIVA (differentiating infected from vaccinated animals) vaccine, which not only induces strong immune responses but also allows for differentiation between infected and vaccinated animals (Herbert et al., 2014). Additionally, a multi-antigenic adenoviral-vectored vaccine has been shown to enhance the protective effects of the traditional BCG vaccine against tuberculosis in goats, reducing lesion volume and bacterial load (De Val et al., 2013). These advancements highlight the potential of modern technologies to improve vaccine efficacy and safety.

### 3.3 Innovations in vaccine delivery systems

Innovations in vaccine delivery systems have focused on enhancing the immunogenicity and stability of vaccines. For instance, a multi-epitope subunit vaccine against goatpox virus has been designed using an immunoinformatics approach, which includes the use of adjuvants like β-defensin to boost immune responses (Long et al., 2024). This approach ensures that the vaccine is non-allergenic, non-toxic, and capable of inducing robust humoral and cellular immune responses. Furthermore, the use of gene knockout technology to create safer vaccines, such as the IL-10 gene-deleted lumpy skin disease virus, has shown promise in providing protective immunity without causing disease. These innovations in delivery systems are crucial for developing more effective and safer vaccines for goats.

## 4 Challenges in Vaccine Development

### 4.1 Pathogen diversity and antigenic variation

One of the primary challenges in developing vaccines for major goat diseases is the diversity and antigenic variation of pathogens. For instance, peste des petits ruminants (PPR) virus exhibits significant strain variation, which complicates vaccine development and efficacy (Enchéry et al., 2019). The virulence of different strains, such as the CI89 and MA08 strains of PPR, varies significantly, necessitating robust challenge models to assess vaccine efficacy across different strains. Additionally, the development of vaccines that can differentiate infected from vaccinated animals (DIVA) is crucial for effective disease control and eradication, as seen in the efforts to create DIVA vaccines for PPR (Herbert et al., 2014).

### 4.2 Regulatory and production barriers

Regulatory and production barriers also pose significant challenges in vaccine development. The production of vaccines that meet international standards for safety and efficacy is a complex process that requires rigorous testing and validation. For example, the ARRIAH live attenuated PPRV vaccine, although promising, is not yet endorsed by the World Organization for Animal Health due to its incomplete safety and potency profile (Byadovskaya et al., 2024). Moreover, the need for thermostable vaccines that can withstand varying environmental conditions without losing efficacy is critical, especially in regions with limited cold chain infrastructure (Murr et al., 2020).

### 4.3 Field application and farmer adoption

The successful field application and adoption of vaccines by farmers are essential for controlling goat diseases. However, challenges such as vaccine accessibility, cost, and the need for multiple doses can hinder widespread adoption (De Pinho et al., 2021). For instance, the efficacy of a pentavalent foot-and-mouth disease (FMD) vaccine in goats was demonstrated, but the requirement for specific dosing regimens may limit its practical application in the field (Lazarus et al., 2020). Additionally, farmer education and awareness are crucial for ensuring proper vaccine administration and achieving desired immunization coverage (Singh et al., 2013). The development of vaccines that provide long-lasting immunity with minimal doses can enhance adoption rates among farmers.

## 5 Case Study

### 5.1 Overview of the selected region or program

The selected case study focuses on the development and deployment of vaccines for major goat diseases in regions heavily impacted by these diseases, such as Africa and Asia. These regions face significant economic losses due to diseases like goatpox, peste des petits ruminants (PPR), and foot-and-mouth disease (FMD) (Lazarus et al., 2020; Zhugunissov et al., 2020). The international community, including organizations like the FAO and OIE, has been actively working towards the eradication of PPR by 2030, highlighting the importance of coordinated vaccination efforts in these regions.

### 5.2 Vaccine development and deployment strategies

Several innovative vaccine development strategies have been employed to combat goat diseases. For instance, a multivalent capripoxvirus-vectored vaccine has been developed to protect against sheeppox, goatpox, PPR, and Rift Valley Fever, demonstrating effectiveness in reducing viral shedding and inducing strong immune responses in sheep and goats (Figure 2) (Boshra et al., 2024). Additionally, a pentavalent FMD vaccine has been tested in goats, showing efficacy in reducing viral shedding and clinical symptoms when administered in appropriate doses. The use of multi-epitope vaccines designed through immunoinformatics approaches has also been explored to enhance safety and immunogenicity against goatpox virus (Long et al., 2024).

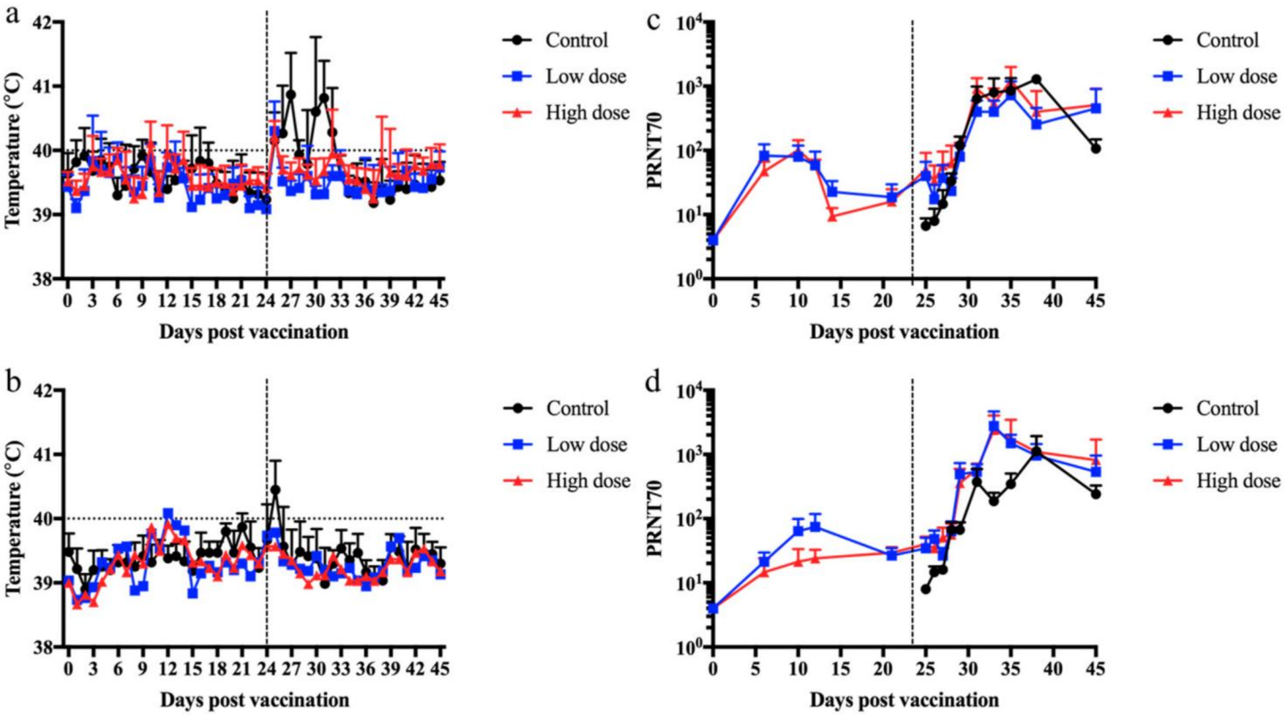


Figure 2 The capripox-PPR-RVFV multivalent vaccine candidate LnRP protects sheep and goats against RVFV infection and elicits neutralizing antibodies (Adopted from Boshra et al., 2024)

Image caption: Sheep and goats were vaccinated with a low dose or a high dose of the LnRP vaccine candidate and subsequently infected with RVFV at 24 days post-immunization. Rectal temperatures of sheep (a) and goats (b) were taken on each indicated day. Sera samples were collected on each indicated day, and RVFV-neutralizing antibodies were detected in sheep (c) and goat (d) samples. Mean values are displayed with the standard deviation (Adopted from Boshra et al., 2024)

### 5.3 Outcomes and lessons learned

The deployment of these vaccines has led to significant reductions in disease incidence and viral shedding among vaccinated goats. For example, the multivalent capripoxvirus-vectored vaccine successfully protected against multiple viral infections, demonstrating the potential of multivalent vaccines in comprehensive disease control. The FMD vaccine trials indicated that even reduced doses could effectively lower viral shedding, suggesting cost-effective vaccination strategies. However, challenges remain in ensuring widespread vaccine coverage and addressing logistical issues in vaccine distribution, particularly in transboundary regions (Zhao et al., 2021). Lessons learned emphasize the need for coordinated vaccination campaigns, scientific evaluation of disease control strategies, and strengthening surveillance and post-vaccination monitoring to achieve long-term disease eradication goals.

## 6 Future Directions in Goat Vaccine Development

### 6.1 Integration of genomics and proteomics

The integration of genomics and proteomics is poised to revolutionize goat vaccine development by providing comprehensive insights into pathogen-host interactions and identifying potential vaccine targets (Qin et al., 2024a). Genomic approaches, such as reverse vaccinology, allow for the high-throughput screening of pathogen genomes to identify antigens that could serve as effective vaccine targets (Seib et al., 2012). Proteomics complements this by characterizing the host's immune response to these antigens, thereby facilitating the identification of immunogenic proteins that can be used in vaccine formulations (Adamczyk-Popławska et al., 2011). This combined approach not only accelerates the discovery of new vaccine candidates but also enhances our understanding of the molecular mechanisms underlying vaccine efficacy (Mora and Telford, 2010).

### 6.2 Role of artificial intelligence and machine learning

Artificial intelligence (AI) and machine learning (ML) are increasingly being utilized to streamline the vaccine development process. These technologies can analyze vast datasets from genomic and proteomic studies to predict potential vaccine candidates and optimize vaccine design (Russo et al., 2020). AI-driven systems biology approaches can model immune responses and predict the efficacy of vaccine candidates, thereby reducing the time and cost associated with traditional vaccine development pipelines. The use of AI in vaccine development is expected to lead to more precise and effective vaccines, as it allows for the rapid identification and testing of novel antigens (Rawal et al., 2021).

### 6.3 Policies and international collaboration

The advancement of goat vaccine development also hinges on effective policies and international collaboration (Donnarumma et al., 2016). The establishment of regulatory frameworks that support the use of in silico trials and AI-driven vaccine development is crucial for the acceptance and implementation of these technologies (Qin et al., 2024b). Furthermore, international collaboration can facilitate the sharing of genomic and proteomic data, as well as best practices in vaccine development, thereby accelerating the development of vaccines for goat diseases that have global significance. Collaborative efforts can also help in addressing challenges such as antimicrobial resistance by promoting the development of vaccines as alternatives to antibiotics (Kaushik et al., 2023).

## 7 Concluding Remarks

The development of vaccines for major goat diseases has shown promising advancements across various studies. The *Mycobacterium tuberculosis* $SO_2$ vaccine demonstrated significant protection against tuberculosis in goats, reducing lesion severity and bacterial load compared to controls. Similarly, the indigenous vaccine for Johne's disease showed superior efficacy in improving physical conditions and reducing mortality and morbidity in goats compared to commercial vaccines. The multivalent Capripoxvirus-vectored vaccine effectively protected against multiple viral infections, including sheeppox, goatpox, and Rift Valley Fever, highlighting its potential for broad-spectrum protection. Additionally, the ARRIAH live attenuated vaccine provided complete protection against peste des petits ruminants (PPR) without clinical signs, indicating its efficacy and safety. These findings underscore the potential of novel vaccine strategies, such as multi-epitope and adenoviral-vectored vaccines, in enhancing immune responses and providing robust protection against goat diseases.

The advancements in vaccine development for goat diseases have significant implications for both policy and research. Policymakers should consider supporting the implementation of these vaccines to improve livestock health and productivity, particularly in regions heavily affected by these diseases. The success of indigenous vaccines and multivalent formulations suggests a need for policies that encourage the development and distribution of region-specific vaccines. Furthermore, research should continue to focus on optimizing vaccine formulations, exploring novel delivery systems, and conducting large-scale field trials to validate efficacy and safety across diverse goat populations. Collaborative efforts between researchers, governments, and the livestock industry are essential to ensure the successful integration of these vaccines into existing disease control programs.

The progress in vaccine development for major goat diseases is a testament to the potential of innovative approaches in veterinary medicine. The integration of immunoinformatics, gene knockout technology, and adenoviral vectors has opened new avenues for creating effective and safe vaccines. As research continues to evolve, it is crucial to maintain a focus on developing vaccines that not only protect against disease but also enhance overall animal welfare and productivity. The ultimate goal is to achieve sustainable disease control, which will contribute to improved livelihoods for farmers and the stability of the livestock industry globally. Continued investment in research and development, along with supportive policies, will be key to realizing the full potential of these vaccines in combating goat diseases.

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## Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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