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Observation Analysis of Vaccine Efficacy in Poultry Farms: Insights from Field Trials on Chicken Immunization

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Abstract This study conducted a comprehensive observation and analysis of the vaccine efficacy in poultry farms, with a focus on evaluating field trials of chicken immunization programs. By evaluating different vaccines in different farm environments, key factors affecting immunization outcomes were identified, and the economic benefits of effective vaccination programs were quantified. The study showed significant differences in vaccine performance, highlighting the importance of optimizing vaccination plans and improving farm management practices, and emphasizing the necessity of continuously improving vaccination strategies and integrating technological advances to enhance efficacy. This study aims to emphasize the key roles of biological, environmental, and operational factors in shaping vaccine performance, providing practical recommendations for policymakers and poultry farmers to strengthen immunization programs and improve poultry health and productivity.

Keywords Poultry vaccination; Vaccine efficacy; Field trials; Poultry farm management; Immunization strategies

1 Introduction

Poultry farming is a critical component of the global agricultural industry, providing a significant source of protein through meat and eggs. However, the industry faces numerous challenges, including infectious diseases that can lead to substantial economic losses. Vaccination is a key strategy in managing these diseases, ensuring the health and productivity of poultry flocks. Poultry vaccination has been a cornerstone in the fight against infectious diseases such as Newcastle disease, avian influenza, and fowl cholera. These diseases can spread rapidly and cause high mortality rates if not controlled effectively. Traditional vaccination methods, such as inactivated and live vaccines, have been employed to induce immunity in poultry, with varying degrees of success depending on the disease and the vaccine used (Hsu et al., 2010). Recent advancements have introduced recombinant vaccines and novel delivery methods, such as spray and oral administration, which are particularly beneficial for smallholder and rural poultry producers (Mebrahtu et al., 2018; Khantour et al., 2021).

The importance of poultry vaccination cannot be overstated, as it plays a crucial role in maintaining the health of poultry populations and ensuring food security. Effective vaccination programs can significantly reduce morbidity and mortality rates, thereby enhancing productivity and profitability for poultry farmers (El-Shall et al., 2021; Samakkhah et al., 2023). Moreover, vaccination helps in controlling the spread of zoonotic diseases, thereby protecting public health. For instance, vaccines against avian influenza not only protect poultry but also reduce the risk of transmission to humans (Kuruppuarachchi et al., 2022).

This study analyzed the efficacy of various vaccines used in poultry farms, with a focus on field trials of chicken immunity. By evaluating different vaccination strategies and their outcomes, insights were provided for the most effective methods of poultry disease prevention, including examining the protective efficacy of vaccines against common poultry diseases, evaluating the impact of different delivery methods, and understanding the role of vaccination in improving poultry health and farm productivity. This study aims to contribute to the development of more effective vaccination plans through analysis, which can be implemented under different agricultural conditions.

2 Overview of Poultry Vaccines

2.1 Types of vaccines used in poultry

Poultry vaccines are essential tools in the prevention and control of infectious diseases in poultry farms. They play a critical role in maintaining the health of poultry, ensuring food security, and minimizing economic losses due to disease outbreaks (Zhou and Lin, 2024). Poultry vaccines can be broadly categorized into live attenuated vaccines, inactivated vaccines, and recombinant vaccines (Table 1) (Wang et al., 2024). Live attenuated vaccines are derived from pathogens that have been weakened so they do not cause disease but still elicit an immune response. Inactivated vaccines, on the other hand, are made from pathogens that have been killed and are safe but may require adjuvants to enhance their efficacy (Bublot, 2023). Recombinant vaccines, including those using virus-like particles (VLPs) and viral vectors, represent a more recent advancement. These vaccines can target multiple diseases simultaneously and are designed to induce a strong immune response even in the presence of maternal antibodies (Romanutti et al., 2020; Raji et al., 2024).

Table 1 Characteristic of conventional vaccines and vector vaccines (Adopted from Wang et al., 2024)

	Inactivated vaccines	Attenuated vaccines	Vector vaccines
Safety	The best security	Some have potential risk of virulence reversion	Some have potential risk of virulence reversion
Effect of the maternal antibody	Depending on the level of antibodies	Depending on the level of antibodies	Some can effectively avoid the interference of maternal antibodies, such as HVT-based vaccine
Duration of immunity	Can only induce a short period of immune protection and requires multiple immunizations	Can induce a long period of immune protection	Can induce a long period of immune protection
Immune response	The onset of protection was short but mainly induced humoral immunity. Some produced only a local response	The onset of protection was long, but both humoral and cellular immunity could be induced	The onset of protection was long, but both humoral and cellular immunity could be induced
Cost	Less expensive	More expensive	Variable

2.2 Common diseases targeted by vaccination

Vaccination in poultry primarily targets viral diseases such as Newcastle disease, avian influenza, Marek's disease, and infectious bursal disease. These diseases are significant due to their impact on poultry health and the potential for economic losses. Recombinant viral vector vaccines have been developed to combat these diseases effectively, offering protection against multiple pathogens with a single vaccine (Hein et al., 2021; Ravikumar et al., 2022). Additionally, infectious laryngotracheitis (ILT) is another disease for which both live attenuated and recombinant vaccines are available, with ongoing research to improve their efficacy (García, 2017).

2.3 Vaccine development and approval process

The development of poultry vaccines involves several stages, including the identification of protective antigens, vaccine formulation, and testing for safety and efficacy. Recombinant DNA technology has facilitated the creation of novel vaccines by allowing the expression of specific antigens in viral vectors, such as fowlpox virus and turkey herpesvirus (Wang et al., 2024). The approval process for these vaccines requires rigorous testing to ensure they are safe, effective, and capable of inducing a protective immune response. This includes evaluating their ability to reduce virus shedding and prevent clinical disease in vaccinated birds (Nielsen et al., 2023). The development of vaccines also considers factors such as cost-effectiveness, ease of administration, and the ability to differentiate vaccinated from infected birds (DIVA strategy) (Suarez and Pantin-Jackwood, 2017).

3 Field Trial Methodologies for Vaccine Efficacy

3.1 Experimental design and farm selection

Field trials for assessing vaccine efficacy in poultry farms involve careful experimental design and farm selection to ensure reliable results. For instance, in a study evaluating the Newcastle disease I2 vaccine, twenty households were randomly assigned to intervention and control groups, with chickens further divided into different intervention groups based on the vaccination method (Mebrahtu et al., 2018). Similarly, another study on avian encephalomyelitis and fowlpox vaccines involved vaccinating chickens in multiple geographical areas to assess the vaccine's safety and efficacy under diverse field conditions. These designs ensure that the trials are representative of real-world conditions and that the results are applicable to a wide range of farming environments.

3.2 Key metrics for assessing vaccine efficacy

Key metrics for assessing vaccine efficacy in poultry include antibody titers, survival rates, and protection against disease challenges. In the Newcastle disease vaccine study, antibody titers were measured to evaluate the immune response, with vaccinated groups showing significantly higher titers compared to controls. Similarly, the efficacy of a live virus vaccine for avian encephalomyelitis and fowlpox was assessed by measuring antibody titers and observing disease protection rates post-vaccination (Sarma et al., 2019). These metrics provide quantitative data on the vaccine's ability to induce an immune response and protect against infections.

3.3 Challenges in conducting field trials

Conducting field trials for vaccine efficacy in poultry farms presents several challenges, including variability in farm conditions, the need for large sample sizes, and logistical issues. For example, the study on Newcastle disease vaccines highlighted the difficulty of maintaining consistent vaccination methods across different farms and the challenge of ensuring adequate sample sizes for statistical significance. Additionally, the study on avian encephalomyelitis and fowlpox vaccines noted the logistical challenges of monitoring large numbers of chickens across multiple locations. These challenges necessitate careful planning and resource allocation to ensure the success and reliability of field trials.

4 Results and Interpretation

4.1 Vaccine performance across different farm environments

The performance of vaccines in poultry farms varies significantly depending on the farm environment and vaccination protocols. For instance, a study on the H5N1 avian influenza vaccine in Indonesia revealed that the effectiveness of the vaccine was highly variable across different farms, with some flocks showing protective immunity while others did not (Tarigan et al., 2018). Similarly, the administration route and vaccination schedule significantly influenced the efficacy of Newcastle disease vaccines, with different methods yielding varying levels of antibody titers and protection (Hassanzadeh et al., 2020). These findings underscore the importance of tailoring vaccination strategies to specific farm conditions to optimize vaccine performance.

4.2 Variability in immunization outcomes

Immunization outcomes in poultry can be highly variable due to several factors, including the type of vaccine, administration route, and farm management practices. For example, the study on Newcastle disease vaccines demonstrated that different vaccination programs and routes of administration led to significant differences in antibody titers and virus shedding among chickens (Sultan et al., 2021). Additionally, the variability in the immune response to Eimeria vaccines was influenced by factors such as the breed of chicken and the husbandry system, complicating the assessment of vaccine efficacy (Soutter et al., 2020). This variability highlights the need for standardized protocols and careful consideration of farm-specific factors to achieve consistent immunization outcomes.

4.3 Economic impact of effective vaccination programs

Effective vaccination programs can have a substantial economic impact on poultry farms by reducing disease incidence and improving productivity. The use of a live Eimeria vaccine in broilers, for instance, resulted in a significant increase in the production index, indicating improved economic performance (Nguyen et al., 2024). Similarly, the implementation of a unique live virus vaccine for avian encephalomyelitis and fowlpox demonstrated high efficacy and safety, leading to reduced mortality and enhanced productivity in vaccinated flocks (Sarma et al., 2019). These examples illustrate that well-designed vaccination programs not only enhance animal health but also contribute to the economic sustainability of poultry operations.

5 Case Study

5.1 Farm characteristics and trial design

The study was conducted across various poultry farms with distinct characteristics to evaluate the efficacy of different vaccines in real-world settings. For instance, in central Ethiopia, smallholder farms were selected to test the Newcastle disease I2 vaccine using different delivery methods such as drinking water and spray, involving 20 households randomly assigned to intervention and control groups (Mebrahtu et al., 2018). Similarly, a large-scale field trial in Morocco involved 18 paired bird houses across 15 farms to assess the safety and efficacy of an aroA-deleted live vaccine against avian colibacillosis. These trials were designed to reflect the diverse conditions under which poultry farming occurs, ensuring that the results are applicable to a wide range of farming practices.

5.2 Trial results and observations

The trials yielded significant insights into vaccine efficacy and safety. In the Ethiopian study, all vaccinated chickens survived a virulent Newcastle disease virus challenge, while only 40% of the unvaccinated group survived, demonstrating the vaccine's protective efficacy (Table 2) (Mebrahtu et al., 2018). In the Moroccan trial, vaccinated groups showed statistically significant improvements in mortality rates, weight gain, and reduced antibiotic use compared to controls, confirming the vaccine's efficacy against colibacillosis. Additionally, a study on a unique live virus vaccine for avian encephalomyelitis and fowlpox showed 100% protection against fowlpox and 97% against avian encephalomyelitis in field conditions, with no adverse reactions reported (Sarma et al., 2019).

Table 2 Number of chicken owned and survived at the end of the study period in Minjar-Shenkora district (Adopted from Mebrahtu et al., 2018)

	No. owned	No. died	No. alive	Survival
Unvaccinated				
Total	151	102	49	32.45%
Average/household	12.58	7.75	4.08	
Vaccinated group				
Total	337	41	296	87.83%
Average/household	21.06	2.56	18.5	

5.3 Key takeaways and lessons learned

The case studies highlight the importance of selecting appropriate vaccination methods and understanding farm-specific conditions to enhance vaccine efficacy. The Newcastle disease I2 vaccine's success in smallholder settings underscores the potential for alternative delivery methods like drinking water and spray to improve vaccination coverage in rural areas. The aroA-deleted live vaccine's performance in Morocco illustrates the benefits of tailored vaccination programs that consider local disease prevalence and farm management practices (Mombarg et al., 2014). These findings emphasize the need for continued research and adaptation of vaccination strategies to meet the diverse needs of poultry farms globally, ensuring both economic viability and animal health.

6 Factors Influencing Vaccine Efficacy

6.1 Biological factors

Biological factors play a crucial role in determining the efficacy of vaccines in poultry farms. Genetic and epigenetic variations among chicken breeds can significantly influence vaccine responses. For instance, microRNAs (miRNAs) have been identified as key epigenetic factors that modulate vaccine efficacy by affecting gene expression related to immune responses. Studies have shown that different genetic lines of chickens exhibit varying levels of miRNA expression, which correlates with their level of protection against diseases like Marek's disease (Zhang et al., 2024). Additionally, the presence of maternal antibodies can interfere with the immune response to vaccines, necessitating the development of vaccines that can overcome this challenge (Meunier et al., 2015).

6.2 Environmental and management factors

Environmental and management factors are critical in shaping the outcomes of vaccination programs in poultry farms. The design and interpretation of vaccine studies often vary due to differences in husbandry systems, breed of chickens, and the conditions under which vaccines are administered. Factors such as the timing of vaccine delivery, the species and strain of pathogens, and the parameters used to assess vaccine efficacy can all influence the results of vaccination trials (Soutter et al., 2020). Moreover, the welfare and performance of chickens, including their housing conditions and nutritional status, can impact their immune responses and, consequently, the effectiveness of vaccines.

6.3 Vaccine handling and administration

Proper handling and administration of vaccines are essential to ensure their efficacy. The method of vaccine delivery, whether injectable or through mass application, can affect the immune response in chickens. Injectable vaccines, while effective, are time-consuming and may not be feasible for large-scale operations, whereas mass-application methods are less common but offer potential for efficiency (Nielsen et al., 2023). Additionally, maintaining the cold chain and ensuring the correct dosage and timing of vaccine administration are crucial to prevent degradation and ensure optimal immune response. The development of recombinant and vectored vaccines has also introduced new considerations for handling, as these vaccines may require specific conditions to maintain their stability and effectiveness (Kapczynski et al., 2015).

7 Strategies for Enhancing Vaccine Efficacy in Poultry Farms

7.1 Optimizing vaccination protocols

Optimizing vaccination protocols is crucial for enhancing vaccine efficacy in poultry farms. One approach is the development of broadly protective vaccines that can simplify vaccination regimens and reduce costs associated with poultry husbandry (Ravikumar et al., 2022). Additionally, the use of DNA vaccines, which can be tailored to induce strong immune responses even in the presence of maternal antibodies, offers a promising alternative (Meunier et al., 2015). The timing and method of vaccine administration, such as in ovo vaccination, can also be optimized to provide earlier immune protection and improve the overall effectiveness of vaccination programs (Li et al., 2023).

7.2 Improving farm management practices

Improving farm management practices is another key strategy to enhance vaccine efficacy. This includes maintaining biosecurity measures to prevent the introduction and spread of infectious diseases (Romanutti et al., 2020). Modifying the gastrointestinal tract microbiome through dietary interventions can also increase the responsiveness of birds to vaccines, thereby enhancing their effectiveness (Alqazlan et al., 2022). Furthermore, co-administration of immunomodulatory agents, such as chicken IL-2, has been shown to alleviate adverse reactions and improve the immune response to vaccines (Hao et al., 2023).

7.3 Integrating technology in vaccination programs

Integrating technology into vaccination programs can significantly improve vaccine efficacy. Targeted delivery of antigens to antigen-presenting cells (APCs) using monoclonal antibodies or ligands can enhance the immunogenicity of vaccines by ensuring that antigens are efficiently presented to the immune system (Shrestha et al., 2018; Shrestha and Iqbal, 2019). Additionally, the use of molecular adjuvants can boost the immune response generated by vaccines, making them more effective against various poultry diseases (Escalante-Sansores et al., 2022). The development of viral vector vaccines that can be administered through mass vaccination methods also represents a technological advancement that can improve the efficiency and coverage of vaccination programs.

8 Future Directions and Recommendations

8.1 Research priorities in poultry vaccine development

Future research in poultry vaccine development should focus on creating more cost-effective and logistically feasible vaccines. The development of multivalent vaccines that do not require chickens for production and can protect against multiple pathogens, such as Eimeria species, is highly desirable (Soutter et al., 2020). Additionally, exploring the use of thermoresistant vaccines, which offer stability and consistent immune responses across different chicken types, should be prioritized (Abdoshah et al., 2022). Research should also aim to identify new antigens and develop novel methods for vaccine antigen delivery to enhance efficacy and protection (Zhang and Lin, 2024).

8.2 Policy and regulatory considerations

Policymakers should consider revising current vaccination protocols to incorporate more effective and safer vaccines, such as the aroA-deleted live vaccine for avian colibacillosis, which has shown significant efficacy and safety in field trials (Mombarg et al., 2014). Regulatory frameworks should support the approval and widespread adoption of innovative vaccines that demonstrate clear advantages over traditional methods, such as the unique live virus vaccine for avian encephalomyelitis and fowlpox, which has been proven safe and effective in large-scale applications. Additionally, policies should encourage the use of vaccines that can be administered through more accessible routes, such as drinking water or spray, to benefit smallholder and rural poultry producers (Mebrahtu et al., 2018).

8.3 Education and training initiatives

Education and training initiatives should focus on equipping poultry farmers with the knowledge and skills necessary to implement effective vaccination programs. Training should emphasize the importance of proper vaccine administration techniques and the benefits of using advanced vaccines, such as those that combine multiple antigens for broader protection (Sarma et al., 2019). Furthermore, educational programs should highlight the role of medicinal plants and supplements, like Immulant® based on Echinacea and Nigella sativa, in enhancing vaccine efficacy and reducing stress-induced pathogenicity in poultry (Eladl et al., 2019). By improving farmer education, the poultry industry can ensure better compliance with vaccination protocols and enhance overall flock health and productivity.

9 Concluding Remarks

The field trials and studies on vaccine efficacy in poultry farms have demonstrated significant advancements in the control of infectious diseases in chickens. The Newcastle disease I2 vaccine, when administered via drinking water and spray, showed protective antibody levels comparable to the eye drop method, ensuring 100% survival against virulent strains. Similarly, a unique live virus vaccine for avian encephalomyelitis and fowlpox was found to be safe and effective, with a 97% protection rate against avian encephalomyelitis and no adverse reactions reported in over 400 million vaccinated chickens. The use of live coccidiosis vaccines in large-scale trials also indicated improvements in production indices, suggesting a viable alternative to anticoccidial drugs. Additionally, the aroA-deleted live vaccine against avian colibacillosis demonstrated efficacy in reducing mortality and improving weight gain in broilers.

Poultry farmers are encouraged to adopt vaccination programs that utilize proven delivery methods such as drinking water and spray for Newcastle disease, which have been shown to be effective under smallholder conditions. Policymakers should support the development and distribution of multivalent vaccines, like the one for avian encephalomyelitis and fowlpox, which offer comprehensive protection and ease of administration. Furthermore, the integration of live coccidiosis vaccines into routine vaccination schedules can enhance productivity and reduce reliance on drugs. It is also recommended to consider the use of aroA-deleted vaccines for controlling colibacillosis, given their demonstrated safety and efficacy.

Vaccination remains a cornerstone in the management of poultry health, offering a sustainable solution to controlling infectious diseases that cause significant economic losses. The studies reviewed highlight the importance of selecting appropriate vaccines and delivery methods tailored to specific farm conditions and disease challenges. Continued research and innovation in vaccine development are essential to address emerging threats and improve the overall health and productivity of poultry populations. The role of vaccination is not only crucial for disease prevention but also for enhancing food security and supporting the livelihoods of poultry farmers worldwide.

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Conflict of Interest Disclosure
The authors affirm 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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