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Review Article

Strategies for Improving Immunity and Production in Broilers: Impact of Vaccination on Poultry Health

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Abstract

This review reviews techniques to enhance immunity and productivity in broilers, explicitly highlighting the effects of vaccination on poultry health. The grill business is integral to the global food supply, and improving grill health and productivity is vital to satisfy the increasing demand for poultry meat. Vaccination is essential for safeguarding poultry from viral illnesses, augmenting their immunological responses, and raising overall production efficiency. The main aim of this review is to analyze the many vaccination procedures utilized in grill production, evaluate their efficacy, and pinpoint research deficiencies. The review consolidates the latest discoveries about vaccine classifications, administration methods, and ideal vaccination timelines. It underscores the correlation between vaccination and immunity, the impact on growth performance and feed conversion efficiency, and the economic advantages of vaccination initiatives. The review also examines problems in vaccination, including vaccine failure, resistance, and environmental factors that affect vaccine efficacy. Furthermore, it examines novel trends in vaccine creation, encompassing the utilization of next-generation vaccines and adjuvants alongside the amalgamation of vaccination with alternative management strategies to enhance health outcomes. The results indicate that vaccination markedly decreases illness prevalence, improves production, and promotes the sustainability of poultry husbandry. It highlights multiple research deficiencies, especially regarding the prolonged impacts of vaccination on immunity and productivity, alongside the obstacles presented by developing diseases and vaccine resistance. Future research should focus on advancing more efficacious vaccines and investigating integrated vaccination techniques that account for environmental and genetic variables. It provides significant insights into contemporary vaccination techniques, their effects on broiler health, and prospective advancements in vaccination strategies within chicken production.

Keywords: Broiler vaccination, poultry health, immunity, production efficiency, vaccine efficacy, emerging diseases, vaccination strategies.

1. INTRODUCTION

Poultry is a key component of world food security and the agricultural economy, especially broiler production. Ensuring maximum broiler health and productivity is a significant issue because of the continuously increasing demand for poultry meat driven by population and income growth. The global production of chicken meat in 2023 was estimated to be over 130 million metric tons, representing almost 40% of the global meat supply (Campbell *et al.*, 2018). The industry has overcome these challenges with remarkable resilience, but there are still many challenges, particularly those associated with the tightrope of broiler health versus productivity (McGinnes *et al.,* 2010). The immune systems of broilers are primarily compromised by diseases, stress factors, and environmental conditions, resulting in poor growth performance and high mortality rates. Vaccination is among the most potent means to ameliorate the adverse effects of the mentioned problem by reducing the allergen burden and reinforcing the immune response against them. While great strides have been made in vaccination protocols, the role of vaccines in conjunction with other immunity-promoting techniques is a changing and nuanced area of study (Dimitrov *et al.,* 2017).

The recent knowledge of poultry health management has highlighted the importance of vaccination in broilers for improving immunity and production efficiency. Vaccination programs help control and prevent diseases such as Newcastle disease, Marek's disease, and avian influenza, thereby alleviating the impact of infectious diseases that interfere with broiler growth and productivity (Cardenas-Garcia *et al.*, 2016). In addition, vaccination helps stimulate a broader immune response, thereby increasing protection and disease resistance, feed conversion efficiency, and survival rates. Despite these advances, we continue to face obstacles in optimizing vaccination strategies. Vaccines do not provide equal protection, and various factors, such as the vaccine's efficacy, administration time, administration routes, and environment, will result in different results. This is compounded by new diseases and the growing demand for more specific, user-friendly, and economical vaccination modalities (Samakkhah *et al.,* 2023).

Despite the importance of this knowledge in monitoring the effects of vaccination on broiler health and production, understanding the interaction between vaccination and immune function in broilers seems to be lacking (Yang *et al.,* 2016). Hence, this review was conducted. Although many studies have been conducted on individual aspects of vaccination, few analyses have integrated the interaction between vaccination features, immune response, and production performance. Some studies have shown that some vaccines are beneficial or hinder diseases; however, the overall economic output available to its immunity has no evident long-term result (Shittu *et al.,* 2016). This gap must be addressed to improve and optimize vaccination programs in commercial poultry populations. This review summarizes the available literature to guide the implementation of these vaccines and their integration with other immune-enhancing processes, including nutrition and environmental management. Identified gaps in the data are discussed, with the hope that this will help guide studies looking to develop future vaccination protocols and improve broiler production efficiency (Annapragada *et al.,* 2019).

This review aims to summarize and combine all available information on the effects of different vaccination strategies on the immune response and performance parameters in broiler chickens. Through examination of both the merits and shortfalls of previous research, this review proposes a new framework for advancing our understanding of how vaccination can be combined with other management interventions to improve the health of broilers (Hugo *et al.,* 2017). This review aims to deliver real-world insights into optimal vaccination schedules, types of vaccines, and administration approaches, all to improve poultry health outcomes (Gao *et al.,* 2019). In contrast to earlier investigations, the current study accounts for the overall effect of vaccination on immune resistance and production performance. The review, via this synthesis, provides novel ideas that should aid poultry producers in developing more efficacious and efficient vaccination strategies and promote the long-term sustainability and profitability of the poultry sector (Dimitrov *et al.,* 2017).

2. Immune System of Broilers

Broilers have complex immune systems comprising several different types of cells, tissues, and organs that provide molecular and cellular defense to pathogens. Optimizing the health and production of broiler chickens requires knowledge of the structure and function of the GIT. The immune system has two main branches: innate and adaptive (Flajnik, 2018). The innate immune response is the initial line of defense, which promptly recognizes and responds to pathogens using physical barriers (such as skin and mucous membranes), phagocytic cells, and the secretion of inflammatory mediators. The adaptive immune system gives a more tailored, focused response by activating T cells and B cells, recognizing specific pathogens, and generating memory cells to protect against future infections (Mehaisen *et al.,* 2017).

Soon after hatching, the immune system in broilers begins to develop, and some maternal antibodies may support it in the initial days of life. Chicks receive these antibodies through the yolk sac to give passive immunity (in the first couple of days). The immune system of broilers develops progressively, gaining the ability to recognize and respond independently to pathogens as they age (He *et al.,* 2019). The sites of infections can be combated with the help of primary immune organs like the bursa of Fabricius, thymus, spleen, and bone marrow; they help produce immune cells to prevent pathogens from entering the body. The bursa of Fabricius is important in the maturation of B cells that make antibodies. The other type of white blood cell, T cells, essential for cell-mediated immunity, must also mature in the thymus (Sonfada *et al.,* 2014).

However, broilers are often subjected to diverse environmental and management stresses that may impair their immune activity. Immune suppression can occur due to environmental stresses like overcrowding, poor ventilation, high stocking densities, and even inadequate nutrition (Ma *et al.,* 2020).

Infections caused by pathogens such as Escherichia coli, Salmonella, and Mycoplasma can exceed the immune system's capacity, increasing broilers' susceptibility to disease (Alzarah *et al.*, 2021). Immune dysfunction is additionally aggravated by hormones changed by stress, inflammatory elements, and damage to organs that play key roles in defense. Such immunocompromised status can decrease the ability of the broiler birds to clear infections, thus decreasing production efficiency and increasing mortality (Sugiharto *et al.*, 2017).

Recent studies indicate that broilers' immune system development is affected by genetic selection and environmental factors, among them vaccination programs. Such programs are intended to elicit a strong immune response from the immune system while preventing disease (Teo *et al.*, 2016). During broilers' growth and maturation, the immune system is essentially the first line of defense for broilers. It considerably affects their productivity when it accompanies vaccines and several other adverse environmental conditions. Therefore, a more profound knowledge of the immune system maturation and the measures to keep it up and running would benefit poultry health and broiler production systems (Ali *et al.*, 2023).

3. Vaccination Strategies in Broilers

Broiler chickens are vaccinated to improve immunity, protect health, and promote productivity. Various vaccination strategies have been developed and implemented over the years to protect against many infectious diseases that can otherwise limit growth rates, feed conversion efficiency, and the general welfare of poultry. Vaccination in broilers aims to induce an immune response against specific pathogens to minimize the risk of infection and achieve better health results (Triosanti *et al.*, 2018).

Poultry vaccines are highly varied, and the vaccine used will often be based on the targeted pathogen, the birds' age, and their route of administration as shown in Figure 1. In general, broiler vaccines can be classified as inactivated (killed), live attenuated (modified live), recombinant, and subunit. Inactivated vaccines contain dead pathogens and produce immunity against certain diseases like avian influenza and Newcastle disease. These vaccines are typically injected and elicit an immune response with no risk of disease (Sabuj *et al.*, 2019). Contrarily, live attenuated vaccines include weakened versions of that actual virus or bacteria employed to provide a strong immune response by simulating natural infection. The vaccines are used via oral, aerosol, or intranasal routes (Wang *et al.*, 2024). Recombinant vaccines are candidate vaccines created by cloning or exogenic expression of pathogen-specific antigens against a pathogen in a nonpathogenic organism using appropriate genetic engineering techniques that result in a selected immune response while avoiding the risks associated with live or inactivated vaccines. As a result, subunit vaccines have various advantages, such as being safe and able to elicit balanced immune responses through specific antigens or parts of pathogens while not being whole organism vaccines that could cause side effects (Zaman *et al.*, 2018).

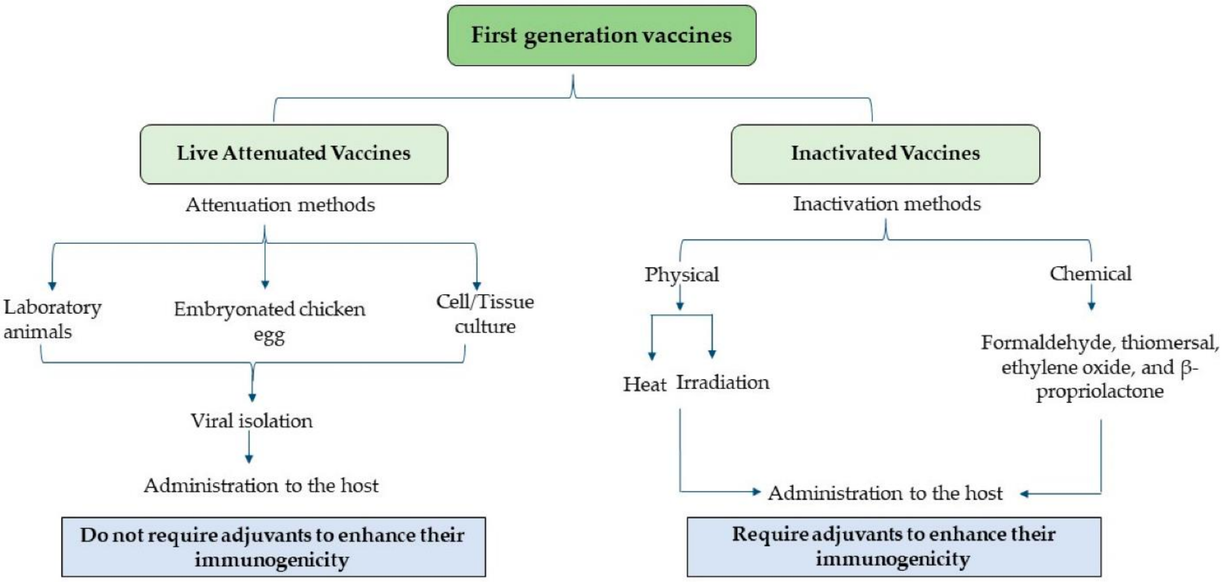

Figure 1

Figure 1: The diagram illustrates the classification and preparation methods for first-generation vaccines, which are divided into two main categories: live attenuated and inactivated. Those attenuation techniques include using laboratory animals, embryonated chicken eggs, and cell/tissue cultures to produce live attenuated vaccines. Such vaccines are administered directly to the host without adjuvants to

boost their immunogenicity. On the contrary, inactivated vaccines are generated via inactivation methods (i.e., heat or irradiation used in physical inactivated vaccines; formaldehyde, thimerosal, ethylene oxide, and β-propriolactone used in chemical inactivated vaccines). Before administering these vaccines to the host, adjuvants are needed to enhance their immunogenicity. It shows how each type of vaccine is produced and what they need to stimulate the immune response (Abdelaziz *et al.,* 2024).

The vaccine administration route is an essential factor in its efficacy as shown in Figure 2. In broilers, vaccines are applied by oral, intranasal, intramuscular, subcutaneously, or through water by using the way for vaccine application. The nature of the vaccine dictates this selection, as do the age of birds and practical aspects like labor cost and ease of application. One example is the delivery mechanism; water-based vaccines are often used in mass vaccination in large flock settings because they are relatively easy to administer. However, getting accurate dosing in all birds is challenging, especially in stressed or unfavorable environmental conditions flocks. These are much more labor-intensive but offer more targeted delivery, especially for the vaccines that need to be packaged with much precision, making the most use of injection-based methods possible (Tang *et al.,* 2022).

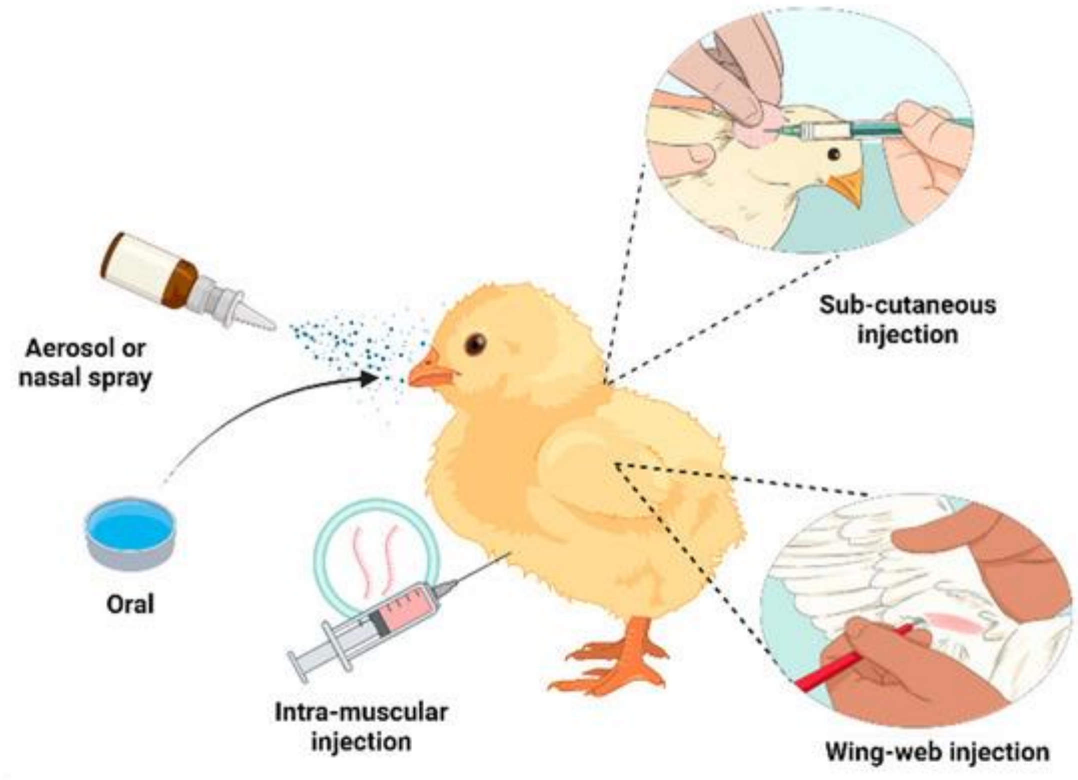

Figure 2

Figure 2: It represents the various routes of vaccination in chicks via aerosol or nasal spray, orally, intra-muscularly, subcutaneously and by wing-web. In the following you can see how each method is performed on the bird. The aerosol or nasal spray method is spraying the vaccine and easier for mass vaccination, while the oral administration method is providing the vaccine through water. Targeted vaccines are usually given via intra-muscular and subcutaneous injections while the wing-web injection is specific to avian species, delivering the vaccine through the wing web. The different routes are chosen depending on the type of vaccine, the stage of development of the bird and the practicality of these approaches in poultry production (Abdelaziz *et al.,* 2024).

Besides the nature and form of administration, timing, and scheduling of vaccines are key determinants in vaccine efficacy as shown in Figure 3. Vaccination schedules in broilers are frequently offered to coincide with development stages in the immunological maturity of these animals to optimize vaccination solutions. Early vaccination, which usually occurs in the first few days of life, helps protect environment and maternal antibodies falling below protective levels during the first few days of life. Booster vaccinations are commonly administered to broilers as they age to maintain protection. Vaccination concerning the bird's age, challenge risk, environmental stressors, and the production cycle are all taken into consideration, and the time of vaccination is such that the vaccines can offer their best protective effect (Dewidar *et al.,* 2022).

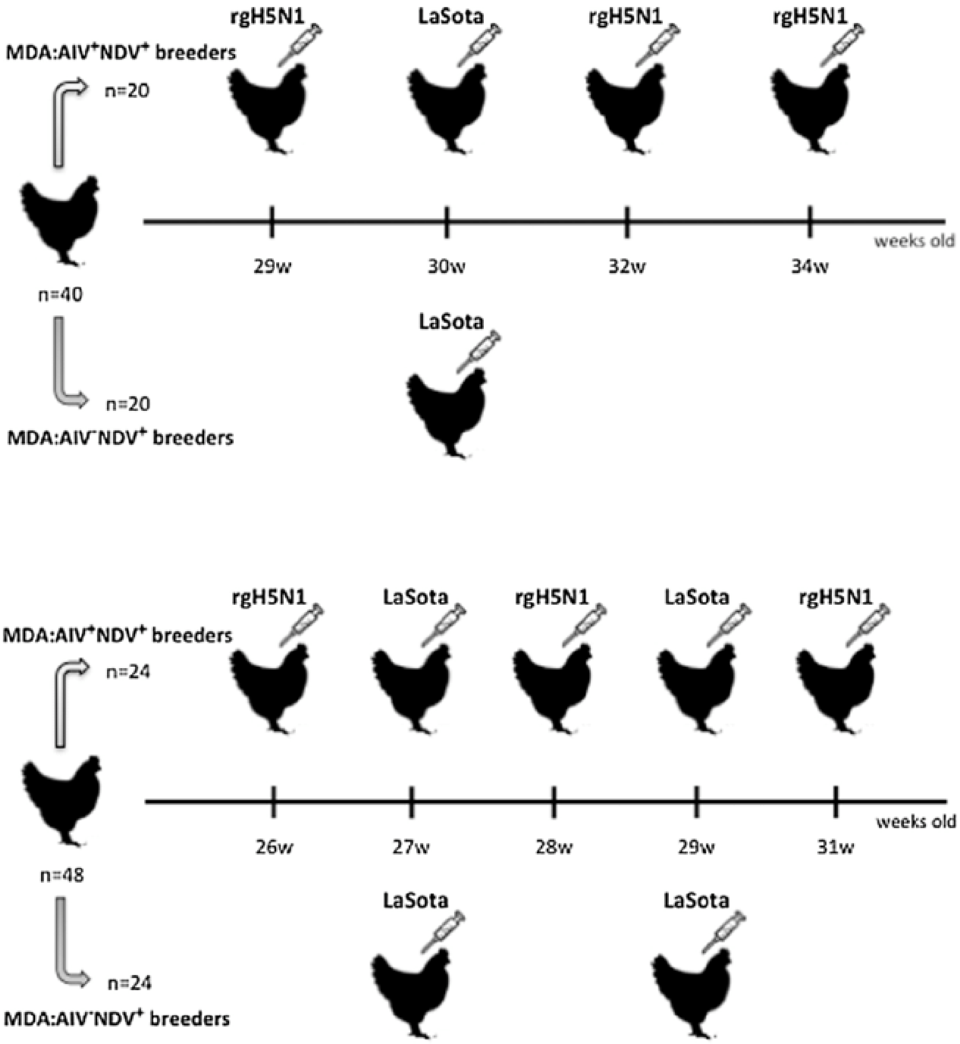

Figure 3

Figure 3: The diagram presents a vaccination schedule for chickens based on age and the specific types of vaccines administered. It compares two groups of breeder chickens, identified as MDA:AIv and NDV**+** breeders, with distinct vaccine types being administered at various weekly intervals. The upper part of the diagram shows a schedule for one group of breeders starting at 29 weeks old, with the vaccines rgH5N1 and LaSota given alternately every few weeks, specifically at weeks 29, 30, 32, and 34. The lower part of the diagram shows another group starting at 26 weeks old, following a similar vaccine administration pattern, with rgH5N1 and LaSota vaccines given at weeks 26, 27, 28, 29, and 31. The overall goal of this vaccination schedule is to assess the immunity conferred by the different vaccines and their effects on the breeders over time. This diagram illustrates how vaccine administration is strategically timed to enhance immunity and manage disease outbreaks effectively in poultry populations.

Although substantial improvements in vaccination approaches, complete efficacy cannot be achieved. Ineffective immune responses may result from vaccine failures due to improper storage, incorrect administration, or genetic variability in broilers. Environmental factors, including stress, nutrition deficiency, and poor management practices, can also decrease vaccine effectiveness. Such problems highlight the need for more precise vaccination protocols tailored to the broilers' health status, genetics, and environment. In addition, new vaccines and adjuvants are substances that help create a stronger immune response, help address emerging diseases and improve vaccine performance against evolving strains of pathogens (Ike *et al.,* 2021).

4. Impact of Vaccination on Poultry Health and Production

Vaccination in poultry can have general effects on dental and affiliation of poultry health and products and bytes such as biological stability, beer for beers, or not drunk but going on performance, love or less fast or speed expression of poultry and survival rate of poultry broilers point. Vaccination approaches aim to strengthen the immune system so broilers can cope with infections that reduce their productivity. The first aim of vaccination is to prevent diseases. However, the various impacts of vaccination on broiler health and productivity are well documented and have been the subject of numerous studies. This section discusses the impact of vaccination on immunity and protection and the associated benefits of vaccination in commercial poultry production (Liu *et al.,* 2019).

Vaccination helps broilers boost their immune response and protects them against poultry-endemic diseases. Vaccines such as those for Newcastle disease, Marek's disease, and avian influenza have the potential to drastically reduce the incidence of these serious infections, which are associated with high rates of mortality or persistent morbidity in poultry. Vaccination induces a response of the innate and adaptive immune systems to produce antibodies and T-cells that provide lasting immunity. This immune priming alleviates the effects of infectious diseases and allows broilers to recover faster from post-infection and show reduced clinical signs. Without vaccines, broilers would be at the mercy of diseases that impair their health, hinder their productivity, induce poor growth rates, and increase mortality (Cho *et al.,* 2018).

However, those vaccines are protective and not just for individual birds. A side effect of vaccination is that it minimizes pathogen load in the environment, yields better general biosecurity, and less spread of diseases within the flock. Poultry house health can be improved with widespread vaccination programs against easily spread pathogens, as the pathogen's spread can be severely limited. Moreover, vaccines can also be used as a prophylactic tool for disease prevention that may result in a secondary infection and require antimicrobial treatment, an important aspect of animal health and an approach to curtail the rising threat of antimicrobial resistance (Eltholth *et al.,* 2016).

Equally important is the effect of vaccination on production outcomes. Vaccination enables broilers to maintain their desired growth trends and feed conversion ratios (FCR) by preventing disease outbreaks. Literature has documented better weight gain and FCR for vaccinated broilers against common poultry diseases over unvaccinated birds. Stress from diseases can significantly suppress growth by reducing feed intake and increasing energy losses due to the immune system working harder to fight infections. Vaccination lowers the incidence and severity of disease outbreaks to ensure no lost production potential for broilers, leading to enhanced weight gain and better feed efficiency (Lupini *et al.,* 2022).

More recently, vaccination has been associated with better survival rates in broiler flocks. Unvaccinated flocks or poorly vaccinated flocks may suffer a large proportion of mortality from disease outbreaks, which will decrease production levels and profits. By contrast, vaccinated birds' mortality rates are lower because they can better combat infections. Using fewer birds that die due to disease reduces mortality, leading to greater production yields and improved profits for poultry producers (Rashid *et al.,* 2013).

Economically, vaccination is a very cost-antagonistic tool for enhancing poultry health and output. Although vaccines and their administration are costly, the benefits of vaccination greatly outweigh these costs in the long run. When flocks undergo vaccination, it is noted that there will be fewer health complications, leading to low veterinary costs, less use of antibiotics, and a low number of birds being lost owing to disease. In addition, this production efficiency—reflected in better weight gain, FCR, and mortality—provides a better return on investment. Vaccination programs targeting infectious pathogens in broiler farms have been reported to be highly profitable as they reduce the losses associated with disease and improve productivity (Islam & Rahman, 2023).

Vaccination improves the sustainable nature of poultry production as well. Vaccination helps address the global challenge of AMR (antimicrobial resistance) increase in agriculture by decreasing the usage of antimicrobial therapies. Using vaccines as a preventative strategy aligns with global initiatives to reduce antibiotic use in livestock, helping to usher in more sustainable, responsible farming practices. This is especially significant as consumers request more ethical and sustainable farming procedures, and laws on animal antibiotic use are tightening (Afkhami *et al.,* 2016).

5. Challenges and Future Directions

Although vaccination has proven benefits in broiler production, the continued use of vaccination presents some challenges regarding maximizing the response to the vaccine or integrating vaccination into a total health program for poultry (Afkhami *et al.,* 2016). These challenges stem from an intersection of technical, environmental, and logistical challenges that may affect the implementation of vaccination campaigns. Strategies to overcome the above-mentioned challenges subsequently pave the way for future directions for vaccination approaches, which are imperative for maintaining the health, productivity, and sustainability of the poultry production system (Enahoro *et al.,* 2021).

One of the main challenges affecting broiler vaccination programs is vaccine failure caused by inadequate storage, handling, and/or administration. Vaccines are usually sensitive to environmental factors like temperature, humidity, and light exposure, which may degrade their potency. Live vaccines, for instance, can degrade if the storage temperature is insufficient or the cold chain is compromised in transport. Furthermore, improper routes of administration may result in insufficient localization of the vaccine for an immune response. Vaccine delivery can also be made without the optimal doses, timing, or methods, particularly in water or aerosol systems, creating suboptimal vaccine uptake and leading to partial flock immunity (Han *et al.*, 2020).

Another significant difficulty is that the immune responses of broilers vary. It has been reported that various factors influence the response of broilers to vaccines, such as genetics, age, nutrition, and environmental conditions. Immunosuppression, stress, or poor health status may inhibit adequate immune response in particular birds, potentially decreasing the effectiveness of vaccination programs (Lyimu *et al.*, 2023). Besides, challenges such as overpopulation, improper ventilation, and inadequate light intensity can reduce immunity to the point where vaccinated broilers still get infected. This variation makes ensuring consistent protection across broad populations challenging, so vaccination strategies must be adapted to individual farms (Redweik *et al.*, 2020).

Emerging diseases, such as new strains of avian influenza and other infectious agents not controlled by currently available vaccines, continue to be a problem for the poultry industry. Pathogen evolution is of particular concern because new variants can evolve to evade current vaccines or immune detection (Xie *et al.*, 2009). This highlights the importance of further enhancing and developing vaccines offering broad coverage against different pathogens. However , many current diseases may develop new variants and updated vaccines and/or polyvalent vaccines are required to control multiple pathogens simultaneously (Wang *et al.*, 2017).

There is also a further challenge in the form of infection-associated vaccine resistance, which presents significant hurdles, particularly in the context of infection with bacteria associated with diseases, for example, Salmonella and Mycoplasma. These organisms do not mutate with the rapidity of viruses. However, strains of reduced vaccine susceptibility can emerge, primarily when vaccination programs are poorly implemented or when there is over-reliance on a single vaccine (Berghaus *et al.*, 2011). The limited availability of vaccines for many bacterial diseases, particularly those caused by non-zoonotic pathogens, adds urgency to the need for the industry to investigate novel vaccination strategies or adjuvants capable of enhancing immune responses (El-Shall *et al.*, 2019).

Vaccination in broiler production has a promising future but must overcome these challenges via innovation and integration in broader poultry health management strategies. It is important to research vaccine innovations to fill the gaps in vaccinations performed by existing programs. There is hope for DNA and nanoparticle-based vaccines as they are more stable and specific than traditional vaccines (Suresh *et al.*, 2025). Directly introducing pathogen genetic material into the bird's cells, a method known as DNA vaccines, can induce humoral and cellular immune responses, providing potential long-lasting immunity with limited side effects. Nanoparticle-based vaccines, by using nanoparticles as antigen delivery vehicles, could provide the potential to stabilize and increase the potency of vaccines by enhancing immune responses (Joshi *et al.*, 2024).

A second important area for future research is using adjuvants—substances that boost the immune response to a vaccine. Adjuvants enable higher and longer-lasting vaccine-induced immunity and could allow lower doses or longer-lasting immunity through fewer doses (Swart *et al.*, 2024). Recent research on plant-based adjuvants and new synthetics that can enhance humoral and cellular immunity will impart a stronger immune response and a wider range of protection against diverse pathogens (Fernandez-Tejada *et al.*, 2016).

More studies on combining vaccinations in complete poultry management systems are needed. Vaccination is not a silver bullet and must be integrated with other management practices such as nutrition, stress management, biosecurity, and environmental management. Optimized birds are sure that broilers remain in good body condition and have a response to vaccination times and a healthy immune system; poultry producers can use these methods to optimize these factors. Several new areas have arisen, including nutritional immunology, which has revealed the possibility that certain dietary supplements (called prebiotics, probiotics, or specific fatty acids) can augment or improve immune function in response to vaccination programs (Cavanagh, 2003).

6. CONCLUSION

In conclusion, this current review demonstrates that vaccination plays an important role in enhancing immunity and, thereby, broilers' production efficiency. Different vaccination strategies have been studied to emphasize the choice of vaccines, routes, and administration schedules to maximize broiler flocks' health and productivity. Immunization strengthens immune response, decreases morbidity rate, increases growth performance, and ultimately results in an efficient feed conversion ratio and survival rate. These findings have broader implications, showing how successful vaccination programs are vital in improving poultry health, reducing economic impact, and enhancing the sustainable poultry industry. Nevertheless, our knowledge surrounding the overall contribution of vaccination to long-term productivity and immunity is incomplete, especially regarding new pathogens and vaccine resistance. New generation vaccines, efficient adjuvants, and vaccination strategy development in combination with feeding, stress, and ambient environment need more attention in the future to reduce infection pressure and minimize the development of AMR in the future. There is also a need for further studies to include inconsistencies in the efficacy of vaccines due to genetic variation and environmental stressors. The main limitation of the present review is the date of the studies, as some of them are older, which may affect the review of the recent technologies in vaccines. Finally, the review does not include all the emerging vaccines or every possible issue a vaccination program faces geographically or environmentally. However, this review adds to the body of literature about COVID-19 vaccination in the broiler sector and provides an overview of the present situation20. It lays the groundwork for future studies, providing a basis for improving health and productivity and supporting the sustainability of the growing poultry industry through the targeting of vaccination strategy.

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