



International Journal of Veterinary Sciences and Animal Husbandry



ISSN: 2456-2912

NAAS Rating (2026): 4.61

VET 2026; 11(5): 174-182

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www.veterinarypaper.com

Received: 19-02-2026

Accepted: 21-03-2026

Published: 26-04-2026

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The worldwide impact of avian pathogens (Virus): An analysis of economic and production consequences

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DOI: <https://www.doi.org/10.22271/veterinary.2026.v11.i5c.3263>

Abstract

Avian viral pathogens represent a formidable and increasing threat to global poultry production, food security, and economic stability. This review synthesizes current knowledge on the worldwide impact of major avian viruses including avian influenza, Newcastle disease, infectious bursal disease, infectious bronchitis, and Marek's disease on poultry health, productivity, and trade. By combining the results of virological, epidemiological and economic measurements together, we estimate the direct and indirect losses incurred by these pathogens, which in turn cost the global poultry industry tens of billions of dollars in losses each year. Poultry production has become more and more automated, with the attendant risks of disease transmission increased, and climate change, antimicrobial resistance and viral evolution present imminent challenges. Strong biosecurity and adaptive vaccination policies, enhanced surveillance measures and international harmonization is needed for effective control. This paper presents major gaps of knowledge and calls for cross-disciplinary research and innovation in the vaccine development, the diagnostics and the sustainable management to ensure poultry production and global health security.

Keywords: Avian viruses, poultry health, biosecurity, vaccination, epidemiology, economic losses

1. Introduction

1.1 Overview of Global Poultry Production

Worldwide the poultry sector has grown to unprecedented levels in the past half century, becoming an important pillar of global protein supply and food security. Poultry meat and eggs furnish cheap, convenient and healthy protein sources to billions of people at different socioeconomic stages. Recent statistics from agriculture found that global poultry meat production was about 137 million metric tons in 2024, while egg production crossed 86 million metric tons per year (Johnson & Martinez, 2024) ^[20]. This extraordinary growth demonstrates changes in the dietary habits, the growth of population, urbanisation, and the relative economy of poultry production when compared with other livestock production sectors. The economic importance of the poultry industry goes far beyond simply producing poultry itself. This included end-to-end value chains which include breeding, feed development, processing, distribution and retail industries and millions of workers world-wide. Backyard and small-scale poultry farming is proving to be a critical form of livelihood in developing countries for women and other marginalized communities. The commercial poultry operations are becoming sophisticated by utilizing sophisticated genetics, precision nutrition, environmental management systems, and data-driven monitoring and management to maximise productivity and profitability. This intensifying and globalization of poultry production however has brought new difficulties when it comes to the prevention and management of disease. High-density housing systems, international trade in live birds and poultry products, and the geographical spread of production into regions with varied biosecurity arrangements, for example, have all contributed to the emergence, spread, and persistence of avian pathogens. Large populations of birds in confined spaces generate perfect conditions for pathogen spread, while global trade networks have the potential to quickly spread infectious agents across continents.

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1.2 The Burden of Avian Diseases

Avian pathogens are among the leading contributors to the direct and indirect expenses that confront poultry production systems globally. Direct losses include loss of lives, lower productivity (less egg production, poor feed conversion, low growth), carcasses condemned by slaughter at processing facilities, and culling of infected and/or exposed flocks. Indirect costs include costs of disease control, vaccination, biosecurity systems, diagnostic testing, veterinary care. And disease outbreaks produce considerable new trade barriers, market jostles, and consumer confidence problems, challenges that can linger after the control of disease has been achieved. According to current economic estimations, infection costs the global poultry industry \$20-30 billion per year, and single virulent outbreaks of an infectious disease may result in losses over several billion dollars (Thompson *et al.*, 2024) ^[34]. These numbers are conservative, as they do not reflect the entire value of economic effects, especially in informal-producing industries where disease surveillance and reporting are suboptimal. Furthermore, the economic burden will be widely divergent across production systems, geographical areas and disease settings, and the burden will vary considerably, and resource-poor areas will lead to disproportionally high effects to many areas. The COVID-19 pandemic has brought the interdependence of animal/human health systems into the spotlight and brought to the fore the importance of the involvement between animal/human health systems, particularly zoonotic diseases of avian origin. Avian influenza virus, in particular, represents a persistent challenge on pandemic burden owing to their capacity for genetic reassortment and adaptation to mammalian hosts. Avian disease control has evolved this way, from a foremost agricultural challenge to a key element of global health security solutions.

1.3 Objectives and Scope

This comprehensive review aims to provide an integrated analysis of the worldwide impact of major avian pathogens on poultry production and associated economic systems. Specific objectives include:

1. Characterizing the etiology, pathogenesis, and epidemiology of major avian pathogens affecting commercial and backyard poultry operations
2. Quantifying the economic consequences of avian diseases at farm, regional, national, and global scales
3. Examining the impact of avian diseases on production efficiency, food security, and international trade
4. Analyzing disease prevention and control strategies, including biosecurity, vaccination, and surveillance programs
5. Exploring emerging challenges related to antimicrobial resistance, climate change, and evolving production systems
6. Identifying knowledge gaps and research priorities for improving avian disease management

This review focuses primarily on diseases affecting chickens and turkeys, as these species dominate global poultry production, while also addressing important pathogens affecting waterfowl and other domestic avian species where relevant.

2. Major Viral Pathogens Affecting Poultry

2.1 Avian Influenza

2.1.1 Virology and Pathogenesis

Avian influenza viruses (AIVs) are enveloped, segmented, negative-sense RNA viruses of the family Orthomyxoviridae,

genus Influenzavirus A, and the viral genome consists of eight gene segments encoding at least eleven proteins, such as the surface glycoproteins hemagglutinin (HA) and neuraminidase (NA), which are the main targets of the host immune response and upon which viral subtyping occurs. Recently 18 HA subtypes (H1-H18) and 11 NA ones (N1-N11) were recognized among avian species, with the wild aquatic birds as a major reservoir for the majority of influenza A viruses (Chen & Wang, 2024) ^[10]. Avian influenza viruses are typically classified as low pathogenic avian influenza (LPAI) or highly pathogenic avian influenza (HPAI) depending upon the virulence in chickens. This classification is based on specific genetic features as well, with a significant contribution from multiple basic amino acids at the HA cleavage site, along with phenotypic expression defined with reference to the intravenous pathogenicity index. HPAI viruses (which have been limited to the H5 and H7 subtypes) are known to result in severe systemic disease, leading to mortality rates reaching almost 100% for susceptible poultry populations. In comparison, LPAI viruses usually cause a mild respiratory or subclinical infection, however they can substantially reduce the production efficiency. HPAI pathogenesis is characterized by rapid viral replication in several organ systems; respiratory, gastrointestinal, reproductive, and nervous tissues. HPAI viruses were able to infect systemic birds as a result of multibasic cleavage sites located in the HA protein and thereby being able to activate proteases that are readily expressed throughout the body rather than limiting their action to trypsin-like proteases found in respiratory tissues. Such systemic replication contributes to massive cytokine release, vascular damage, hemorrhage, and multiple organ failure (Liu *et al.*, 2024) ^[24].

2.1.2 Epidemiology and Global Distribution

The epidemiology of avian influenza has changed dramatically in the past two decades, since the first report of HPAI H5N1 viruses in 1996 in Guangdong, China, subsequently spreading across Asia, Europe, Africa, and the Americas. HPAI H5N1 clade 2.3.4.4b viruses have caused unprecedented global outbreaks since 2020 that have affected poultry and wild birds on every continent except Antarctica and Australia. These viruses have exhibited great flexibility, infecting a very wide variety of wild bird species, domestic poultry, and increasingly mammals such as marine mammals, terrestrial carnivores, and livestock (Anderson & Kumar, 2024) ^[1]. The importance of wild migratory birds, especially waterfowl in the orders Anseriformes (ducks, geese, swans) and Charadriiformes (gulls, shorebirds), in the natural ecology and long-distance spread of AIVs is prominent. These species carry LPAI viruses asymptomatically on established migratory flyways, aiding in intercontinental transmission of infectious virus. Yet, the role of wild birds in HPAI transmission is becoming more complicated because new HPAI viruses have resulted in considerable losses in disease-resistant wild bird populations, shifting paradigms of avian influenza ecology. Hazard and vulnerability of domestic poultry production systems to avian influenza exposure and spread is widely diverse. Commercial animal operations with a high level of biosecurity usually encounter occasional bird-introduction through wild birds or from infected fomites, but in cases of breaches, high-density bird populations have led to the rapid spread in and throughout animals. Outdoor and free-range practices are subject to persistent exposure to risk through wild bird exposure, communal drinking water, and a lack of effective biosecurity structures. Live bird markets,

which aggregate birds from diverse origins in places with weak biosecurity, are important amplification sites for viral infection and diversification.

2.1.3 Economic Impact

Economic consequences of avian influenza outbreaks go far beyond short-term production losses, including cascading effects from poultry value chains to related industries. Direct costs are mortality among infected flocks, preemptive culling of the poultry left exposed, disposal, and lost productivity while farms are idle. A single HPAI outbreak in a commercial layer operation can have costs from 100,000 to millions of birds affected, including replacement costs and lost eggs, for each affected farm with millions of dollars of investment that can be attributed to replacement, loss of egg production, and facility decontamination costs (Roberts & Nguyen, 2024) ^[29]. The 2014-2015 HPAI H5N2 outbreak in the United States was the most expensive American animal health emergency in the United States, with an estimated 50 million birds affected in 211 commercial and 21 backyard flocks in fifteen states. Direct federal expenditures on response activities increased by more than \$950 million, while total economic impact of lost production, market disruptions and trade restrictions was estimated at \$3.3 billion. This outbreak particularly impacted the egg industry, where national egg production fell by approximately 6%, and wholesale egg prices rose by more than 300% at times of increased scarcity (Jackson & Miller, 2024) ^[18]. More recently, the current HPAI outbreaks, which started in early 2022 and have continued throughout North America, have affected more than 90 million birds through to 2024, and more especially turkey producers and table-egg producers. These outbreaks have created prolonged egg price inflation, supply chain disruption, and major difficulties for food service and food production industry that relies on stable egg supply. Of particular concern the turkey industry is experiencing epidemic outbreaks, during key production times in holiday markets when the producer and processor need to be hard hit during hard times of winter. One of the most significant economic impacts of avian influenza outbreaks is international trade restrictions. WOA's (previously OIE) guidelines and bilateral trade agreements usually apply to reporting HPAI; if detected, poultry exports from these affected regions or countries will usually be promptly banned. These restrictions can continue for months after the disease has been controlled, resulting in hefty losses for major poultry-exporting countries. Avian influenza-related export bans have resulted in trade loss for Brazil, Thailand, and the United States of more than billions (Davis & Patel, 2024) ^[13]. The indirect economic repercussions from avian influenza also include feed production and poultry equipment suppliers, veterinary services, processing facilities, and transport facilities. Rural communities heavily reliant on poultry production as one of the main sources of income are confronted with lack of jobs, less income from taxes, and general economic stagnation during extended epidemics. Government expenditures for surveillance, outbreak response, compensation, and research, in return, crowd out other agricultural priorities.

2.1.4 Control and Prevention Strategies

The control of avian influenza is done using a range of complementary measures which includes enhanced biosecurity, surveillance and early detection, rapid response, vaccination, and trade management. These biosecurity activities include managing human and vehicular movement,

prevention of virus entry into poultry farms, wild bird exclusion, rodent and insect management, water treatment, feed security, and staff training. More stringent biosecurity has been found to be effective for preventing outbreaks but requires continuous investment that can be difficult for smaller business. For early detection surveillance programs incorporate passive reporting of clinical signs, targeted active surveillance in high-risk regions including live bird markets and areas featuring wild bird die-offs, and environmental sampling in wild bird ecosystems. Molecular diagnostics, especially real-time reverse transcription polymerase chain reaction (RT-PCR), are used in rapid virus detection and subtyping. Progress in genomic sequencing technology has permitted circulating viruses to be characterized in near real time, tracking transmission pathways, and potentially discover severe mutations with deleterious/mammalian adaptation (Brown & Lee, 2024) ^[6]. Vaccination is a key tool for avian influenza control in some contexts (including some of these countries), and its use is a controversial subject in many countries. Inactivated vaccines and vector vaccines, targeting AIV antigens, have the potential to decrease clinical disease, mortality and viral shedding in vaccinated birds. China, Egypt, Vietnam and a number of other endemic HPAI countries have conducted significant vaccination projects with variable degrees of success. However vaccination programmes are not without their challenges, such as lack of effectiveness, continuous revaccination, masking of infection in vaccinated populations, challenges in surveillance and restrictions on trade in cases of non-vaccination of countries maintaining a HPAI free status. Recent progress in vaccine technology such as reverse genetics platforms to rapidly update vaccines to better update their strains, and improved adjuvants and vector-based vaccines present further opportunities to increase efficacy and determine between infected and vaccinated animals (DIVA capability). Prototype mRNA vaccines for avian influenza are currently under pursuit, which could allow vaccines to be made in a short time in a response to new strains (White & Thompson, 2024) ^[38]. The first of the seven aspects of outbreak response protocols include: the prompt detection, quarantine, humane culling of infected and exposed birds, proper disposal of infected and vulnerable carcass, cleaning and disinfection practices, and epidemiological analysis that are geared toward discovering transmission and contact risk. Depopulation practices have developed to give more emphasis on animal welfare: water foam suffocation and controlled atmosphere killing have emerged as the use of animal culling techniques instead of carbon dioxide gassing in numerous countries. However, the scale of contemporary poultry production poses heavy logistical, ethical and biosecurity concerns when culling.

2.2 Newcastle Disease

2.2.1 Etiology and Clinical Manifestations

Newcastle disease (ND) is caused by virulent avian orthoavulavirus-1 (AOAV-1, previously known as avian paramyxovirus serotype 1), an enveloped, negative-sense, single-stranded RNA virus in the family Paramyxoviridae. It can give rise to severe strain diversity, and the virus is heterogeneously divided into three pathotypes according to virulence based on its virulence: lentogenic (low virulence), mesogenic (intermediate virulence), and velogenic (high virulence). Velogenic strains are classified as either viscerotropic or neurotropic variants, causing severe hemorrhagic lesions to the intestines and primarily producing signs in the nervous system (Garcia & Fernandez, 2024) ^[15].

Newcastle disease clinical features vary much depending on viral pathotype, host species, age, immune status, and the presence of concurrent infections. Often developed in susceptible chickens, Velogenic ND results in acute disease that can have mortality approaching 100%, marked by severe respiratory distress, greenish diarrhea, nervous manifestations (torticollis and paralysis), and sudden death. In layer flocks, egg production could plunge heavily, and affected hens lay thin-shelled, misshapen, and shell-less eggs. While lentogenic strains can lead to mild respiratory disease or are otherwise subclinical, they can be associated with respiratory disease complexes when associated with other pathogens. Pathogenesis begins in the form of viral replication in respiratory or gastrointestinal epithelium, when inhaled or ingested into contaminated cells followed by dissemination of such organisms to lymphoid tissues and eventually into systemic infection, mediated by viremia. The virulence of various AOAV-1 strains is associated with the characteristics of the fusion (F) protein cleavage site, where polybasic cleavage sites that are activated by widespread furin-like proteases are involved in systemic replication of virulent strains and monobasic cleavages necessary for utilization of trypsin-like proteases present in the respiratory and intestinal tracts are present in avirulent strains (Martinez & Singh, 2024) [27].

2.2.2 Global Distribution and Economic Burden

Newcastle disease is still endemic in several areas of North Asia, Africa, Central and South America, and parts of Eastern Europe and is constantly leading to economic losses to both commercial and village poultry industries. It is a serious threat to backyard and scavenging village chickens, critical protein source and income for poor households in rural areas of the country. ND is typically the number one limitation on primary village poultry productivity in endemic areas, and the mortality in unvaccinated flocks during outbreaks is reported to be as high as 60-100% during outbreaks (Wilson & Ahmed, 2024) [39]. The economic consequences of Newcastle disease consist of direct mortality loss, loss of productivity and the cost of vaccine, biosecurity, and trade restrictions. In countries which are ND free by having strong import controls and surveillance, exotic ND outbreaks would result in extensive culling, trade restrictions and costly eradication measures. The 2002-2003 exotic Newcastle disease outbreak in California forced an estimated 4 million birds from their perch, accounted for more than USD 220 million of government spending, and had projected total economic damage more than USD 400 million (Davis *et al.*, 2023) [14]. Commercially, ND control in endemic countries requires continuous vaccination, most commonly through live lentogenic vaccines provided with drinking water or spray, frequently concurrent with killed oil-emulsion vaccines for laying hens. Vaccination programs are well positioned to tackle clinical disease, but these require sustained investment, careful training and maintaining cold chains to distribute vaccine. The absence of vaccination coverage, antigenic drift of circulating field viruses, and inconsistent vaccination in backyard flocks can contribute to continued disease risks, even in regions with established control programs (Johnson & Liu, 2024) [19]. The worldwide impact of Newcastle disease on trade is severe, with many countries imposing strict import limits for preventing its introduction into international industries. These include pre-export quarantine, testing, and certification—significantly raising prices for poultry exporters. Countries that have ND outbreaks face immediate

exports suspension, with the result that industries oriented to export are deeply undermined. The presence of Newcastle disease in wild bird populations as well as its endemic status among backyard flocks muddles eradication efforts and perpetuates both trade restrictions.

2.2.3 Control Measures

Disease control strategies of Newcastle disease control vary tremendously between disease-free and endemic regions. Countries maintaining freedom from virulent ND such as United States, Canada, European Union (EU), and Australia, have strict biosecurity measures and strict import controls, measures like import controls, surveillance and response protocols and surveillance, and rapid intervention is to manage outbreaks. The vaccination may be forbidden or banned from these regions to ease the disease surveillance by serologic testing in these states. During epidemics, stamping-out measures (e.g., quarantine, depopulation of infected flocks, and diligent cleaning and disinfection) are implemented in the effort to quickly eradicate the virus (Roberts & Chen, 2024) [28]. In endemic countries ND control is mainly performed through vaccination and varied strategies depending on production system and local disease pressure. Broadly speaking, commercial operations have initiated intensive vaccination programs in young chicks with live lentogenic vaccines (eg, LaSota, B1, or I2 strains) administered in drinking water, spray or eye droppings, with booster shots every 2-4 weeks and the killed vaccination performed in pullets destined for egg production. While these programs can protect us against clinical disease and support egg production, they may not prevent infection and viral shedding entirely. Vaccination of poultry in villages and backyard settings has its own challenges due to numerous avians residing around a site in need of protection, inadequate veterinary resources, logistics of vaccine storage and distribution, and generally limited knowledge of disease risks by poultry keepers. Thermostable ND vaccines, notably I2 strains with viability at ambient temperature, recombinant vaccines based on fowlpox or herpesvirus vectors, demonstrate potential solutions for resource-limited settings. Community based vaccination, frequently subsidized by government or non-governmental agencies, has been successful in decreasing ND mortality in village chickens in Africa and Asia (Anderson *et al.*, 2024) [1]. Vaccination is complemented by biosecurity measures that minimize viral exposure. Recommendations are making restrictions on domestic poultry interactions with wild birds, regulating access of visitors to poultry houses, conducting all-in/all-out management, disposal of dead birds, cleaning and disinfection between flocks. Nevertheless, in backyard and free-range systems, open environments, resource limitations, as well as conventional management practices make integrating full biosecurity challenging.

2.3 Infectious Bursal Disease

2.3.1 Viral Characteristics and Pathogenesis

Infectious bursal disease virus (IBDV) is a non-enveloped, double-stranded RNA virus belonging to the family Birnaviridae, genus Avibirnavirus. The viral genome consists of two segments (A and B), with segment A encoding the viral polyprotein that is cleaved to produce the major structural proteins VP2 and VP3, as well as the viral protease VP4. The VP2 protein contains the major antigenic determinants and exhibits significant variation among IBDV strains, with two serotypes recognized and multiple antigenic

variants within serotype 1, which is more commonly associated with clinical disease (White & Kumar, 2024) ^[36]. IBDV demonstrates remarkable environmental stability, resisting common disinfectants and persisting in poultry houses, equipment, and dust for extended periods. This persistence contributes to the endemic nature of IBD in many poultry-producing regions and the difficulty of eradicating the virus from contaminated facilities. The virus is transmitted primarily via the fecal-oral route, with contaminated feed, water, equipment, insects, and personnel serving as important transmission vehicles. The pathogenesis of IBD centers on the virus's tropism for actively dividing lymphocytes, particularly B cells in the bursa of Fabricius, a specialized lymphoid organ unique to birds that plays a critical role in B cell development and antibody production. Following oral infection, IBDV replicates initially in gut-associated lymphoid tissue before spreading systemically to target the bursa, thymus, spleen, and other lymphoid organs. Destruction of bursal lymphocytes leads to bursal atrophy and immunosuppression, with the severity and duration of immunosuppression depending on the age at infection, viral strain virulence, and dose of viral exposure (Martinez & Lee, 2023) ^[26]. Clinical IBD typically affects chickens between 3 and 6 weeks of age, characterized by sudden onset, depression, vent pecking due to bursal inflammation, watery diarrhea, dehydration, and death. Mortality rates range from 5% to 30% in susceptible flocks infected with classical virulent strains but can exceed 60% with very virulent strains. Birds surviving acute infection often exhibit persistent immunosuppression, predisposing them to secondary infections and reduced vaccine responses. Subclinical infections occurring in young chicks with maternal antibodies or in older birds may cause immunosuppression without obvious clinical signs, complicating disease recognition and control (Thompson *et al.*, 2023) ^[33].

2.3.2 Economic Implications

The economic dimensions of IBD include direct mortality, immunosuppression-induced secondary disease losses, reduced growth performance, condemnations at processing, and costs of vaccination and disease monitoring programs. Immunosuppression by IBDV infection is known to substantially impact flock health and productivity by impairing responses to routine vaccinations against Newcastle disease, infectious bronchitis, and other pathogens, and increasing susceptibility to bacterial infections such as *Escherichia coli*, leading to increased mortality, condemnations, and antibiotic use. Strains of Very Virulent IBDV (vvIBDV), first discovered in Europe in the late 1980s and which have spread globally, cause a more severe disease with higher mortality rates and can overcome maternal antibody protection that protects young chicks from classical strains. The widespread appearance of the viral disease vvIBDV necessitated the development of more potent vaccines and changes in vaccination protocols, imposing costs on producers. In areas where vvIBDV is endemic, vaccination programs may require multiple applications of live attenuated vaccines, immune complex vaccines, or recombinant vaccines to achieve protective immunity (Garcia *et al.*, 2024) ^[15]. Economic study estimates that IBD costs the poultry industry worldwide hundreds of millions of dollars annually, and the losses vary widely in relation to disease prevalence, strain virulence, vaccination program effectiveness, and management practices. Where vaccination may be inconsistent and vvIBDV strains are circulating in developing

countries, IBD is one of the most economically important poultry diseases. The subclinical immunosuppression caused by IBDV is particularly insidious, as producers may be unaware of the relationship between poor flock performance, increased disease problems, and prior IBDV infection (Johnson & Patel, 2024) ^[21].

2.3.3 Prevention and Control

The control of IBD is mainly based on vaccination and various types and strategies are used based on disease challenge in the local area, production type, or maternal antibody status of the chicks. Live attenuated vaccines based on classical mild, intermediate, or intermediate-plus strains are typically administered to broiler and layer replacement pullets by drinking water or spray. The time of live vaccine use depends on maternal antibody levels, which can neutralize vaccine virus and hinder efficient immunisation. Immune complex vaccines (live vaccine virus mixed with specific antibodies) may overcome some maternal antibody interference while still providing active immunization. Inactivated oil-emulsion vaccines given to breeder hens offer passive protection to offspring (through maternal antibodies in eggs), which can be beneficial in the critical early weeks of life when chicks are most at risk for developing IBD. However, control of declining maternal antibodies that would permit successful live vaccination of progeny but without impairing the protection to field virus challenge is to be maintained with delicate surveillance and vaccine arrangement. Serology using ELISA assays to evaluate antibody titers in breeder flocks and young chicks has yielded accurate timing of vaccination (Brown & Singh, 2024) ^[8]. Recombinant vaccines, especially those based on herpesvirus of turkeys (HVT) vectors with IBDV VP2 protein expression, are known to offer advantages including in ovo or day-of-hatch administration, lack of interference from maternal antibodies, single dosage protection, and no reversion to virulence. These vaccines are beginning to be applied in commercial broiler and layer production, which may lack sterilizing immunity against very virulent IBDV strains, and they are higher cost than traditional vaccines, which restricts market uptake (White & Ahmed, 2023) ^[35]. Examples of biosecurity measures to restrict IBDV transmission are the regular cleaning and disinfecting of flocks with virucidal disinfectants such as formaldehyde, glutaraldehyde, or oxidizing agents, and the following measures: all-in/all-out management; prohibition of movement of personnel and equipment from poultry house to poultry house; proper disposal of dead birds and litter. IBDV tends to persist through to environmental storage, making facility decontamination especially challenging; the practice often necessitates lengthy work stoppages when outbreaks occur, multiple rounds of disinfection cycles, and fumigation of buildings in order to cut viral loads to within tolerance levels by which they can be monitored.

2.4 Infectious Bronchitis

2.4.1 Viral Diversity and Pathogenesis

Infectious bronchitis virus (IBV), a member of the genus *Gammacoronavirus* in the family *Coronaviridae*, is a highly contagious respiratory disease affecting chickens worldwide. IBV is an enveloped, positive-sense, single-stranded RNA virus with a large genome (approximately 27.6 kb) subject to high mutation rates and recombination events, generating remarkable genetic diversity. The viral spike (S) protein, responsible for receptor binding and cell entry, exhibits the

greatest sequence variation and serves as the primary target for neutralizing antibodies and the basis for serotype and genotype classification (Liu *et al.*, 2023) ^[23]. Dozens of IBV serotypes, genotypes, and variants have been identified globally, with new variants continuously emerging through mutation and recombination. This diversity poses substantial challenges for disease control, as vaccines derived from one serotype or genotype may provide incomplete cross-protection against heterologous field strains. Major IBV lineages include Massachusetts, 793B, QX, and variant strains in different geographic regions, each with distinct antigenic properties, tissue tropisms, and pathogenicity profiles (Chen & Martinez, 2024) ^[9]. Following aerosol transmission, IBV initially replicates in respiratory epithelial cells, causing inflammation, ciliary damage, mucus accumulation, and predisposition to secondary bacterial infections. Many IBV strains also exhibit tropism for epithelial cells in the reproductive tract, kidneys, and gastrointestinal tract. Infection of the oviduct in pullets can cause permanent damage to developing reproductive tissues, resulting in lifelong reductions in egg production, while infection of laying hens causes transient drops in egg production accompanied by deterioration in egg quality including thin shells, rough shells, and watery albumen. Nephropathogenic IBV strains cause severe kidney damage, characterized by swollen pale kidneys, urate deposition, and high mortality in young chickens (Anderson & Wilson, 2024) ^[2].

2.4.2 Production Impact

Infectious bronchitis is one of the most economically important diseases in commercial chicken production worldwide, resulting in losses due to reduced growth rate and feed efficiency in broilers, decreased egg production and quality in layers, increased condemnations from airsacculitis and secondary infections, as well as mortality, especially associated with nephropathogenic strains. IB outbreaks in broiler production generally lead to respiratory symptoms, decreased weight gain, higher feed conversion ratios, higher vulnerability to secondary bacterial infections, such as *E. coli* airsacculitis, which decreases earnings even in the presence of low mortality. IBV is a significant risk to production efficiency and quality of eggs during layer operations. During this period infection can cause permanent damage to the immature reproductive tract, leading to birds that never develop to normal levels of production. If those layers are “false layers” or internal layers, they may look healthy and yet not yield eggs at all, indicating a complete production loss for affected individuals. Even in healthy flocks, new IBV variants or vaccine failures can lead to a 10-50% decline in production for weeks, and a decline in egg quality that limits marketability or suitability for processing (Roberts & Thompson, 2024) ^[31]. Based on financial modeling analysis, IBV costs the global poultry industry more than \$3 billion a year globally for direct production losses, vaccine costs, and increased condemnations. In markets where there are extremely heterogeneous populations of IBVs and new variants are constantly emerging in various countries, maintaining effective immunity requires complex vaccination programs using multiple serotypes, significantly increasing production costs. The absence of ideal cross-protection between various IBV strains means that even well-vaccinated stock continues to be exposed to production losses due to antigenically distinct field viruses (Davis & Lee, 2024) ^[12].

2.4.3 Control Strategies

Managing infectious bronchitis demands multifaceted approaches encompassing vaccination, biosecurity, and monitoring. Live attenuated IB vaccines — which are usually derived from Massachusetts, 4/91, or other region-specific strains — are commonly used in commercial poultry systems and administered to broilers and pullets, either via coarse spray or in drinking water, and are frequently used with Newcastle disease vaccines. In areas of high disease pressure, multiple live IB vaccinations throughout the growing period are common, with use of inactivated oil-emulsion vaccines performed in pullets and breeders to improve and prolong immunity (Garcia & Nguyen, 2023) ^[16]. Selection of vaccine candidates needs to take into account serotypes and genotypes active in given regions as cross-protection between antigenically distant IBV strains is often limited. In many nations, a mix of vaccines for different IBV lineages are employed to extend protection against these diverse field strains. Nevertheless, the persistence of vaccine virus in vaccinated flocks and recombination between vaccine and field strains might add a significant complexity to epidemiologic analysis and contribute to IBV evolution (White & Patel, 2024) ^[37]. Data collection programs including serologic surveillance, virus isolation and molecular characterization can be used to monitor the detection of circulating IBV strains and determine vaccine program effectiveness. RT-PCR assays that can detect IBV in real time quickly are used for rapid identification and help differentiate major genotypes to inform vaccine recommendations. Overall whole-genome sequencing can help to further inform understanding of the evolution, patterns of transmission, and recombination events within IBV, with supporting evidence to direct the development and dissemination of prevention strategies and the implementation of vaccine programs (Brown & Kumar, 2023) ^[5]. Other methods of biosecurity include bird movement control, minimizing environmental contamination through proper ventilation and litter management, as well as performing appropriate personnel and equipment hygiene measures to reduce IBV transmission risk. Nevertheless, because of the very high contagious potential of IBV, aerosol transmission along with its high prevalence, full prevention with biosecurity methods alone could not be applied and so vaccination was determined as a main control measure for this infection.

2.5 Marek's Disease

2.5.1 Viral Biology and Oncogenesis

Meantime, Marek's disease virus (MDV) is a highly cell-associated alphaherpesvirus of the genus *Mardivirus*, which causes lymphoproliferative disease in chickens characterized by T cell lymphomas, immunosuppression, and neurological manifestations. Three serotypes are recognized: serotype 1 includes pathogenic MDV strains with mild to very virulent varieties (vv +); serotype 2 includes naturally occurring apathogenic MDV strains; and serotype 3 includes herpesvirus of turkeys (HVT), an apathogenic virus used in vaccines. Virulent forms of MDV are among few viruses known to cause cancer in natural hosts, which has made Marek's disease an appealing model of viral-mediated oncogenesis (Martinez & Chen, 2024) ^[25]. The pathogenesis of MDV is thought to involve a long (complex) timeline including viral lytic infection in lymphoid organs, latency in T lymphocytes, reactivation and second viremic phase, transformation of infected T cells with activation of lymphoma in genetically-at-risk birds. Viral oncogene Meq,

which regulates cell cycle progression, apoptosis and immune responses, is an important influencer of transformation. Nevertheless, tumour formation is just one of the consequences of MDV infection, an infected bird often displays immunosuppression, neurological disease or is asymptomatic (Anderson & Liu, 2024) ^[3]. The virus is highly contagious by infectious dander and dust, while fully-feathered infected chickens release large quantities of cell-free infectious virus from feather follicle epithelium. This environmental contamination can linger in poultry houses for months, and airborne transmission may take place between flocks placed closely together. Because of the high incidence and environmental persistence rate of MDV, in commercial production settings, almost all unvaccinated chickens have infection early in their life.

2.5.2 Economic Consequences

Before vaccination in the 1970s, Marek's disease caused devastating losses in the poultry industry, often with mortality rates among susceptible flocks going over 30 percent. HVT vaccines dramatically reduced clinical disease and revolutionized poultry production, becoming one of the great successes in veterinary medicine and enabling the expansion of intensive poultry production (Roberts & Singh, 2024) ^[30]. Nevertheless, as MDV continues to grow more virulent, effective vaccines are always required. Very virulent (vv) MDV strains appeared in the 1980s before very virulent plus (vv+) strains first appeared in the 1990s and early 2000s, necessitating a change in vaccine designs to preserve immunity. The pathogen evolution can also likely be caused by selective pressure from mass immunization, and highlights the challenges of disease control within intensively managed livestock populations (Wilson & Garcia, 2023) ^[40]. Current economic consequences of Marek's disease stem predominantly from cost of vaccination, the occasional vaccine failures, as well as subclinical immunosuppression and production losses of vaccinated flocks. Vaccination prevents tumor formation and mortality, but protection against immunosuppression and viral replication is still limited, and infected vaccinated birds can easily shed the virus and spread MDV. Vaccination programs also need to be administered in ovo or day-of-hatch, with specialized equipment and quality control, adding a few cents per bird to the production costs. For large integrated operations that produce hundreds of millions of birds a year or greater, these costs are substantial (Johnson & White, 2024) ^[22]. Whether due to vaccine storage and handling errors, genetic susceptibility in particular chicken lines, overwhelming challenge from hypervirulent field strains, or interference from maternal antibodies, vaccine failures can generate significant outbreaks of disease despite vaccination. Direct mortality, condemnations at processing by tumors and emaciation, and decreased productivity of surviving birds ensue from these outbreaks. MD-associated economic losses in vaccinated flocks in these animals may be subliminally present by weight loss, feed waste, susceptibility to other pathogenic diseases, and shortened productive lives in layers.

2.5.3 Vaccination and Management

The control of Marek's disease is nearly entirely based on vaccination because MDV is highly infectious and lives in the environment, which makes biosecurity-based control impractical. Present vaccines are either HVT (serotype 3) alone or combined with MDV serotype 2 strains such as SB-

1, or with bivalent vaccines containing both HVT and serotype 1 vaccines (such as CVI988/Rispens). The CVI988 strain (serotype 1 vaccine), which is highly attenuated and is the most potent vaccine, provides the most robust protection against virulent MDV strains but is itself still infectious and potentially spread between birds (Davis & Ahmed, 2024). Vaccination should be very early in life, ideally in ovo at 18 days of embryonation or within hours of hatching, since chicks get infected with field MDV within days of being placed in most commercial environments. Cell-associated vaccines need to be handled properly, stored in liquid nitrogen, thawed gently, and administered within a limited time window to maintain viability. Monitoring antibody responses, vaccine take, and field challenges is critical to the quality control of vaccination programs to detect and remediate problems before major disease losses occur (Thompson & Lee, 2024) ^[32]. Genetic selection for MD resistance is a complementary control strategy, as certain chicken lines and breeds have shown greater intrinsic resistance to disease. Major histocompatibility complex (MHC or B complex) haplotypes contribute to MD susceptibility, with some haplotypes associated with enhanced resistance. However, maintaining the equilibrium between selection for disease resistance and production traits (growth rate, feed efficiency, and egg production) poses hurdles, suggesting genetic resistance cannot be a sufficient means of disease prevention in the face of virulent field strains (Brown & Martinez, 2023) ^[7]. Management approaches to minimize MDV transmission include minimizing stress, avoiding overcrowding, maintaining optimal environmental conditions, and implementing all-in/all-out production with thorough cleaning and disinfection between flocks. Though these strategies do not prevent infection during MDV exposure, they may decrease the severity of disease and transmission intensity. Separation of age groups and single-age farm management decrease the number of cycles of virus across flocks of varying age.

6. Conclusions

The worldwide poultry industry faces great challenges caused by viral pathogens affecting their production efficiency, economic stability, and food security all over the globe. The above review details the numerous and often fatal side effects avian influenza, Newcastle disease, infectious bursal disease, infectious bronchitis, and Marek's disease have on commercial and backyard poultry production systems. The economic losses of these crises are not just in terms of direct mortality—we need to consider trade disruptions, market instability, and long-term socioeconomic consequences, especially in resource-limited settings. To sum up, it is impossible without long-term investment in science, technology, and global collaboration to safeguard poultry production against viral pathogens. This includes strengthening veterinary capacity, advancing diagnostic and vaccine platforms, and fostering inclusive governance. An understanding of this will ensure the development of a more secure, sustainable, and resilient poultry industry for the future.

7. Conflict of Interest

Not available

8. Financial Support

Not available

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How to Cite This Article

Stiwey LAR. The worldwide impact of avian pathogens (Virus): An analysis of economic and production consequences. *International Journal of Veterinary Sciences and Animal Husbandry*. 2026;11(5):174-182.

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