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## LITERATURE REVIEW

# Avian Influenza in Colombia: A One Health Perspective on Surveillance, Intervention, and Policy Integration

***Influenza Aviar en Colombia: una perspectiva de salud única sobre vigilancia, intervención e integración de políticas.***

***Gripe aviária em Colombia: uma perspectiva de saúde única em vigilância, intervenção e integração de políticas.***

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## Abstract

**Background:** Avian influenza remains a significant global health issue, threatening animal and human populations. The natural reservoirs of influenza A viruses (IAV) are wild birds, and their transmission dynamics can influence disease outbreaks in domestic poultry and humans. Colombia, due to its geographic location and diverse ecosystems, faces unique challenges in surveillance and control of avian influenza. **Objective**: This work aims to provide a comprehensive overview of avian influenza in Colombia from a One Health perspective, highlighting surveillance, intervention strategies, and policy integration to mitigate disease spread. **Methods**: A literature review was conducted to consolidate data on avian influenza cases in Colombia, including reports on outbreaks in poultry and wild birds. Risk factors, transmission routes, and prevention strategies were analyzed, emphasizing the role of migratory birds and ecological influences. **Results**: Colombia has experienced highly pathogenic avian influenza (HPAI) outbreaks, primarily affecting backyard poultry and wild birds. The review identifies key risk areas influenced by migratory bird pathways, poultry farming practices, and biosecurity measures. Effective surveillance systems and rapid response protocols are essential to prevent further spread. **Conclusions**: Adopting a One Health approach that integrates veterinary, public health, and environmental efforts is critical to mitigating avian influenza in Colombia. Strengthening surveillance, improving vaccination strategies, and enhancing biosecurity measures can reduce transmission risks. International cooperation is also necessary to monitor migratory bird movements and implement preventive measures against potential outbreaks.

**Keywords**: *avian influenza; Colombia; global health; multisectoral collaboration; One Health, public health policies.*

## Resumen

**Antecedentes:** La influenza aviar sigue siendo un problema de salud pública a nivel global, representando un riesgo para poblaciones animales y humanas. Las aves silvestres son reservorios naturales de los virus influenza A (IAV), y su dinámica de transmisión puede influir en la

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presentación de brotes en aves domésticas y humanos. Colombia, por su ubicación geográfica y diversidad de ecosistemas, enfrenta desafíos únicos en la vigilancia y control de la influenza aviar. **Objetivo:** Este trabajo tiene como objetivo proporcionar una visión integral de la influenza aviar en Colombia desde la perspectiva de Una Salud, resaltando estrategias de vigilancia, intervención e integración de políticas para mitigar la propagación de la enfermedad. **Métodos:** Se realizó una revisión de literatura para consolidar datos sobre casos de influenza aviar en Colombia, incluyendo reportes de brotes en aves de corral y silvestres. Se analizaron factores de riesgo, transmisión y estrategias de prevención, con énfasis en el papel de las aves migratorias y la influencia ecológica. **Resultados:** Colombia ha experimentado brotes de influenza aviar altamente patógena (IAAP), afectando principalmente aves de traspatio y silvestres. La revisión identifica áreas de alto riesgo influenciadas por rutas migratorias, prácticas de producción avícola y medidas de bioseguridad. La implementación de sistemas de vigilancia efectivos y protocolos de respuesta rápida es clave para prevenir la propagación del virus. **Conclusiones:** La adopción de un enfoque de Una Salud que integre esfuerzos veterinarios, de salud pública y ambientales es fundamental para mitigar la influenza aviar en Colombia. El fortalecimiento de la vigilancia, la mejora en estrategias de vacunación y la implementación de medidas de bioseguridad pueden reducir el riesgo de transmisión. Además, la cooperación internacional es esencial para monitorear el movimiento de aves migratorias y establecer medidas preventivas contra posibles brotes.

**Palabras clave:** *colaboración multisectorial; Colombia; influenza aviar; políticas de salud pública; salud global; Una Salud.*

**Resumo**

**Antecedentes:** A gripe aviária continua sendo um problema de saúde pública global, representando riscos para populações animais e humanas. As aves selvagens são reservatórios naturais dos vírus da influenza A (IAV), e sua dinâmica de transmissão pode influenciar surtos em aves domésticas e humanos. A Colômbia, devido à sua localização geográfica e diversidade ecológica, enfrenta desafios específicos na vigilância e controle da gripe aviária. **Objetivo:** Este estudo visa fornecer uma visão abrangente da gripe aviária na Colômbia a partir de uma perspectiva de Saúde Única, destacando a vigilância, estratégias de intervenção e integração de políticas para mitigar a propagação da doença. **Métodos**: Foi realizada uma revisão da literatura para consolidar dados sobre casos de gripe aviária na Colômbia, incluindo registros de surtos em

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aves domésticas e selvagens. Foram analisados fatores de risco, rotas de transmissão e estratégias de prevenção, com ênfase no papel das aves migratórias e na influência ecológica. **Resultados:** A Colômbia registrou surtos de gripe aviária altamente patogênica (HPAI), afetando principalmente aves de quintal e selvagens. A revisão identifica áreas de alto risco influenciadas por rotas migratórias, práticas de avicultura e medidas de biossegurança. Sistemas eficazes de vigilância e protocolos de resposta rápida são essenciais para evitar a propagação do vírus. **Conclusões:** A adoção de uma abordagem de Saúde Única que integre esforços veterinários, de saúde pública e ambientais é crucial para mitigar a gripe aviária na Colômbia. O fortalecimento da vigilância, a melhoria das estratégias de vacinação e a implementação de medidas de biossegurança podem reduzir os riscos de transmissão. Além disso, a cooperação internacional é essencial para monitorar o movimento das aves migratórias e implementar medidas preventivas contra surtos potenciais.

**Palavras-chave:** *colaboração multissetorial; Colômbia; gripe aviária; saúde global; One Health; políticas de saúde pública.*

## Introduction

Influenza is a significant global health concern due to its potential impact on animal and human populations. This emerging infectious disease, primarily caused by type A influenza viruses (IAV), has been the subject of extensive study worldwide as increased incidence has been observed over the past decades [1]. IAVs have caused one of the more prevalent acute respiratory diseases, with millions of severe illnesses and human deaths throughout history [2]. Besides the regular seasonal outbreaks caused by human IAV, infections may be caused by IAV from animals, notably birds and swine [3]. Therefore, added to the seasonal burden of IAV in humans, there is a constant risk of developing novel IAV strains with pandemic potential [4]. In Colombia, the presence and dynamics of animal influenza pose significant challenges to public health and agricultural sectors. Understanding the current landscape of avian influenza in Colombia is essential for devising effective prevention and control strategies. This introduction sets the stage for a comprehensive examination of bird influenza in Colombia, emphasizing the need for research and multidisciplinary collaboration to address this complex issue. The aim of this work is to consolidate existing research on avian influenza, offering a comprehensive understanding of its

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prevalence, impact, and management strategies. This paper emphasizes the importance of a One Health approach, advocating for enhanced multisectoral collaboration between veterinary, medical, ecological, and public health sectors. It seeks to highlight factors and vulnerable regions susceptible to outbreaks, promote early detection systems, vaccination programs, and to integrate several considerations for public and animal health decision makers to protect both animal and human populations in Colombia.

## Eco-epidemiology of Avian influenza virus

The eco-epidemiology of the avian influenza virus encompasses the intricate interplay between ecological factors and the epidemiology of the virus within avian populations and their environments. Avian influenza, caused by various subtypes of IAV, poses significant threats to animal and human health worldwide. Understanding the eco-epidemiology of IAV is essential for elucidating the transmission dynamics, spatial distribution, and risk factors associated with avian IAV outbreaks.

Influenza viruses are negative-sense single-stranded RNA viruses in the family Orthomyxoviridae. There are four types (A, B, C, and D), of which only types A and B are the most relevant for animal and human health [5]. Their genome comprises 8 segments (Figure 1) with a total length of ~13.6 kb [6]. Type A Influenza viruses are categorized into subtypes based on their surface proteins, hemagglutinin (HA) and neuraminidase (NA). To date, 19 types of HA and 11 types of NA have been recognized [7,8]. Over 130 influenza A subtype combinations have been identified in nature, primarily from wild birds, considered the natural reservoir of influenza A viruses (IAVs) with the greatest diversity of subtypes [9]. Only type A influenza viruses (IAV) are known to cause natural infections in avian species. The HA protein is essential in cell entry and interactions with the host immune system, while the NA protein catalyzes viral release from infected cells [10].

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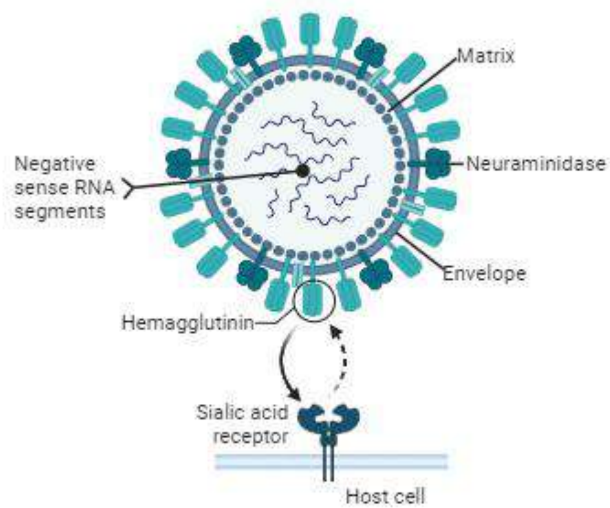


**Figure 1**. Schematic diagram representing the structure and composition of type A Influenza Virus. Two surface proteins, hemaglutinin (HA) and neuraminidase (NA). The matrix protein and the viral envelope are derived from the host plasma membrane. The ribonucleoprotein complex is where each viral RNA segment is covered with nucleoproteins and a polymerase and serves as a fundamental unit for the transcription and replication of the viral genome. Created in Biorender.com

Influenza A viruses are highly adaptable, evading host immune responses and infecting new host species [11]. This is mainly because the RNA-dependent RNA polymerase, an enzyme that catalyzes the replication of the viral RNA, is error-prone. Therefore, there is no error correction during virus replication. In addition, the segmented genome structure of the virus allows genetic re-assortment, which is the exchange of entire segments between viruses co-infecting a cell, a primary process for virus evolution [12].

Host tissue tropism is a crucial element for the transmission of IAV. For example, in avian hosts, most IAV primarily infects intestinal tissue and, to a lesser degree, respiratory organs, which are thus shed via feces and respiratory secretions. Thus, the pathogenicity of avian influenza also varies. IAVs generally cause mild disease in wild birds [6]. However, some strains (e.g., H5N1) can cause systemic and highly pathogenic disease in avian and mammal hosts [13–15]. Influenza A viruses that infect poultry can be categorized into two groups according to their capacity to induce illness in chickens [16]. There is a current designation for IAVs as high or low-

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pathogenicity strains based on the severity of illness in poultry. The hallmark of highly pathogenic IAV is the presence of specific mutations in the hemagglutinin (HA) gene, particularly in the cleavage site, allowing the virus to be processed by a wider range of enzymes, facilitating systemic infection in birds when compared to similar low pathogenicity forms [17–19]. The group of viruses causing low pathogenic avian influenza (LPAI), can cause an asymptomatic or mild disease, and in contrast, viruses causing highly pathogenic avian influenza (HPAI) cause a severe disease with rapid mortality [16].

The ecology of IAV depends on the complex virus transmission patterns, which are driven by interactions between the host community, the environment, and co-evolution between the host and pathogen [20]. Globalization, climate change, land use, and other factors from anthropogenic environmental changes have altered the ecology and evolution of IAV; therefore, understanding these complex relationships would enable the identification of ways to mitigate the emergence of the following pandemic strains [21–23]. To date, there is a vast knowledge of ecological and molecular determinants responsible for the IAV interspecies transmission. Most documented transmission events are focused explicitly on avian-derived influenza subtypes, which involve zoonotic and epizootic transmission to other hosts (Figure 2).

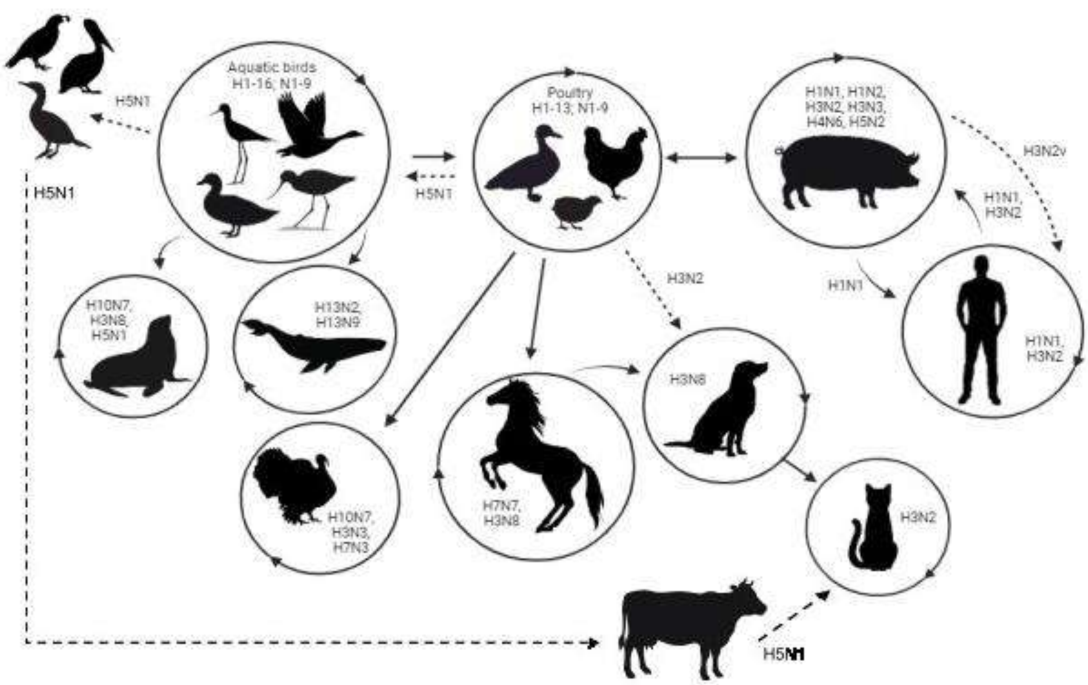

**Figure 2**. Representative diagram of interspecies transmission events of Influenza A viruses and the subtypes involved in these events. Solid arrows represent direct transmission events with sustained transmission. Dashed arrows represent sporadic infections with no sustained transmission. Created using Inkscape.

**Avian Influenza Current Landscape**

Avian influenza represents a significant infectious disease threat to wild bird populations and domestic poultry worldwide. Aquatic birds of the orders Anseriformes (ducks and geese) and Charadriiformes (shorebirds and gulls) are the primary reservoir of IAV. These group of species have been found infected with most known IAV subtypes [24]. Co-infections in the same avian host of two viral subtypes enable the reassortment of viral genetic segments and have helped spawn the diversity of IAV strains globally [20]. In addition, the high diversity and spread of some of these viruses are linked to the migratory nature of the wild bird species [25–28]. Viruses are shed in bird feces and later acquired by other birds with the same habitat along migratory flyways [27,29–31]. Thus, the migration of wild birds between locations poses a persistent risk of transmission of avian influenza [27,32].

In passerine birds, the low prevalence of infection has suggested that they act as spillover hosts, however, some peri-domestic species (such as house sparrows) may be involved in virus spread between poultry farms [4]. Pigeons have been naturally infected and susceptible to highly pathogenic avian influenza. However, their role in virus transmission remains unknown [33]. Several factors affect IAV transmission in avian populations. Among them, virus shedding, stability in the environment, and the degree of interaction with other species are the most described [34]. Prolonged virus shedding from bird species facilitates the efficient transmission of IAV in aquatic ecosystems [31]. The environmental persistence and infectivity of IAV depend on several ecological factors, including atmospheric and environmental conditions [35–38]. Also, virus shedding is related to the age and development of the avian immune system [39,40].

In poultry, the introduction and spread of avian IAV can have devastating effects, leading to high mortality rates and significant economic losses [41,42]. The rapid transmission of avian IAV within densely populated poultry farms can result in widespread outbreaks, requiring stringent

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biosecurity measures and rapid response protocols to prevent further dissemination [43]. The emergence and spread of avian influenza, particularly in poultry, has become a growing global concern, with both HPAI and LPAI strains posing significant threats to animal health, public health, and international trade [44].While waterfowl and other wild birds seem to be responsible, either directly or indirectly, for most IAV transmissions to domestic poultry, other possibilities should not be dismissed [45]. For example, IAV can be transmitted from infected pigs to poultry [46]. Also, the virus spread by personnel and fomites or shared contaminated water or food may become relevant in transmitting IAV in poultry [47].

Since the 90s, outbreaks of LPAI in poultry have been commonly reported in several world locations [47]. However, sporadic outbreaks of HPAI have been of significant concern due to their pandemic potential and considerable threat to public health [48]. HPAI has also catastrophically impacted backyard poultry [20,49–51]. Transmission of HPAI viruses from domestic poultry to wild bird populations has also been reported [42]. Since 2014, a highly pathogenic avian influenza virus of H5 subtpe, particularly clade 2.3.4.4, has caused global outbreaks in domestic poultry, occasional transmission to humans, and a growing number of deaths among various wild bird species [25].

Furthermore, diagnostic techniques and laboratory testing play a critical role in the prevention, control, and surveillance of avian influenza. Rapid and accurate detection of the virus through molecular methods, such as RT-PCR testing, allows for timely intervention to contain outbreaks and prevent further spread [52,53]. In countries like Colombia, where the poultry industry is vital for the economy, the ability to quickly detect and respond to avian influenza is crucial. Thus, limited access to advanced diagnostic infrastructure, poses challenges, making it harder to contain outbreaks and prevent spillover into human populations, potentially leading to economic and public health impacts [54–56]. Strengthening laboratory capacities and international collaborations is essential for countries like Colombia to effectively manage the threat of avian influenza.

**Human-animal health and avian influenza**

The interface between human and animal health plays a crucial role in the epidemiology and control of infectious diseases, including avian influenza. Animal influenza, particularly avian and

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swine influenza, can have important consequences for human health because of the possibility of transmission between animals and humans [57]. In rare instances, avian IAV can cross the species barrier to infect humans, leading to severe respiratory illness and, in some cases, death [58]. Several avian IAV strains have been fatal in a small proportion of infected individuals, most of whom had close contact with domestic poultry [31,59]. Notable examples include the H5N1 and H7N9 avian IAV, which have caused sporadic outbreaks in humans with high mortality rates in certain instances [60]. The outbreak of H7N9 in China, which caused high morbidity and case fatality in humans, has been one of the more severe zoonotic infections from avian IAV [61,62]. Poultry markets have been demonstrated to harbor a variety of IAVs [63–65]. Since 2019, individuals in 17 countries within five continents have been reported as infected with avian IAV from five emerging subtypes (H5N8, H10N3, H3N8, H10N5, and H5N2) and four re-emerging subtypes (H5N1, H5N6, H7N9, and H9N2) [60].

In recent years, the role of backyard poultry in the transmission dynamics of IAV has garnered increasing attention. Backyard poultry, often kept by households for subsistence or small-scale production purposes, can serve as reservoirs for various influenza strains, including those with zoonotic potential [66]. While commercial poultry operations have historically been the focus of surveillance and control efforts, backyard poultry populations have emerged as significant contributors to influenza transmission due to their proximity to humans and other animals and limited biosecurity measures [67–69]. The interaction between backyard poultry and humans presents a unique challenge in influenza management. In this scenario, individuals who maintain backyard flocks are often in close contact with their birds, increasing the risk of zoonotic transmission of IAV [70]. Furthermore, mixing diverse bird species within backyard settings can facilitate the exchange of influenza viruses, leading to novel reassortant strains with unpredictable pathogenicity and transmissibility [71]. In Colombia, the recent outbreak of avian influenza significantly impacted backyard poultry (Fig 3.). The virus, introduced through migratory wild birds, spread quickly among domestic flocks, leading to high mortality rates in affected areas [72]. Backyard birds, often raised in less controlled environments, are particularly vulnerable to infection due to close contact with wild birds and lack of biosecurity measures. Despite their importance in influenza ecology, backyard poultry populations are often overlooked in surveillance and control strategies [73]. Limited resources, infrastructure, and awareness among

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backyard poultry keepers compound the challenges of monitoring and managing influenza outbreaks in these settings [67,70]. Nevertheless, proactive measures such as educational campaigns, improved biosecurity practices, and enhanced surveillance efforts can help mitigate the risk of IAV transmission in backyard poultry populations and reduce the potential for zoonotic spillover events [74,75].

Throughout human history, four influenza pandemics—occurring in 1918, 1957, 1968, and 2009—have resulted in millions of deaths worldwide [2,76]. The most recent pandemic, which occurred a decade ago, was caused by a novel reassortant strain of IAV H1N1 subtype. This strain, which originated in Mexico, contained genetic material from swine, avian, and human influenza viruses [77]. While efforts to prevent and control influenza have largely focused on the 2009 H1N1 pandemic strain, there are deep concerns over the pandemic potential of avian IAV, particularly the HPAI H5N1 subtype, which has become panzootic in poultry globally [78]. While H1N1, a human-adapted virus, demonstrated its pandemic potential during the 2009 outbreak, spreading rapidly through human-to-human transmission and affecting millions globally [79], among the avian strains, the H5N2, primarily a bird-adapted virus, is causing widespread outbreaks in poultry with devastating effects on agriculture [80]. Although H5N2 has limited human infections, its potential to reassort or mutate poses a future threat of cross-species transmission [81]. Also, the H5N1 IAV subtype has garnered significant attention due to its imminent pandemic risk and its high fatality rate in humans [82,83]. Recent outbreaks of H5N1 IAV in animals such as alpacas, cats, cattle, and humans across North America [84–87] clearly illustrate the interconnectedness of human and animal health in the context of zoonotic diseases. These cases highlight the critical need for robust surveillance, early detection, and control measures to prevent the emergence of novel influenza strains with pandemic potential [48,57].

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**Agriculture, globalization, land use, climate change and influenza**

The interplay between agriculture, globalization, land use, climate change, and influenza represents a complex web of factors influencing IAV transmission and emergence dynamics. Changes in agriculture practices due to globalization and shifts in land use have transformed landscapes and ecosystems, thus changing the dynamics among humans, animals, and the environment [88,89]. These alterations can significantly impact the ecology and epidemiology of IAVs, influencing how they spread, survive, and evolve [90,91].

Avian IAV H5N1 (clade 2.3.4.4b) has recently emerged as a highly pathogenic strain with significant implications for livestock, including outbreaks affecting cows and other domestic species in the United States [92]. While avian influenza primarily impacts birds, the spread of the virus to cattle poses a unique threat to the agricultural sector. Outbreaks among livestock can lead to severe economic losses, as affected herds may require quarantine and testing to prevent further spread [93]. As mentioned before, some avian species (passerine birds) may play a role as possible vectors for dissemination of IAV, such as LPAI H7N9 strain [94], a virus that has caused infections in humans and poultry in Asia [95,96]. Thus, The interconnection between humans, wildlife, and domestic livestock, particularly through shared environments and water sources, heightens the risk of transmission [97], and effective control measures will be essential to mitigate the impact of these outbreaks on the animal industry and maintain agricultural stability [75].

Globalization has enabled swift transportation of goods, individuals, and animals across borders, fostering greater interconnectedness among regions and continents [98]. Intensive livestock production systems, characterized by large-scale farming operations and high animal densities, such as pork production, have become common in many parts of the world to meet the demands of a growing global population [99]. However, these systems can create ideal conditions for the emergence and spread of IAV, promoting transmission between animals and facilitating spillover events to humans [100,101].

Changes in land use, driven by urbanization, deforestation, and agricultural expansion, can alter the habitats of wildlife and domestic animals, bringing them closer to humans [102]. This encroachment into natural ecosystems can disrupt ecological balances and increase the risk of cross-species transmission of zoonotic viruses [103]. Additionally, climate change can potentially influence the distribution and behavior of influenza hosts, such as migratory birds, further complicating efforts to predict and control influenza outbreaks [104].

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Ecosystems, such as wetlands, provide critical ecological services and habitat for wild birds; however, over the past centuries, these natural ecosystems have been subjected to anthropogenic changes for development, agriculture, and domestic water use [4,105]. Land use transformation and the increased demand for freshwater by humankind, in association with global climate change, are expected to alter the availability of natural wetlands drastically [4]. But, some species, like waterfowl, have well adapted to human-altered landscapes and prospered over the past decades [106,107]. The impact of these changes in avian influenza ecology is unexplored. Changes in land use that result in higher concentrations of waterfowl, stress, or close proximity to domestic birds are likely to result in the heightened transmission of influenza within flocks and transmission across different species [108,109]. Using IAV surveillance data from 2006–2020 in Denmark, researchers identified strong associations between IAV and landscape factors, particularly coastal areas and wetlands, which significantly influenced IAV presence due to the attraction of waterfowl and migrating birds [110]. A recent research on the migration of northern pintail and Eurasian wigeon in the East Asian-Australasian Flyway demostrated the role of these species in the avian IAV transmission, with both species showing a preference for rice paddies, increasing outbreak risks in these rapidly changing landscapes [111]. Another study highlighted the significant role of wild waterfowl, particularly Anatidae species, in the transmission of avian IAV to domestic livestock, specifically poultry, through shared habitats. GPS telemetry data revealed that wild ducks frequently utilized dairy and beef cattle feed lots, retention ponds, and occasionally poultry facilities for roosting and foraging, increasing the risk of IAV transmission [112].

In addition, universities and other institutions play a crucial role in the research, management, and prevention of avian influenza outbreaks. Through interdisciplinary research, they contribute to understanding virus transmission dynamics, developing vaccines, and improving diagnostic techniques [113]. Universities also collaborate with public health agencies to create evidence-based strategies for disease control and prevention [114,115], training future scientists and policymakers in the process [116]. Furthermore, their role in public awareness campaigns has been key in preventing the spread of misinformation during outbreaks [117,118].

Thus, the complex interactions between agriculture, globalization, land use, ecology of avian influenza resorvoirs/hosts and climate change underscore the need for a One Health approach to

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influenza surveillance and control [119,120]. By acknowledging the interdependence of human, animal, and environmental health, policymakers and researchers can create comprehensive approaches to reduce the impact of this disease on public health and agriculture [121]. These approaches may include improved biosecurity practices, early warning systems for emerging diseases, sustainable land management practices, and efforts to mitigate climate change. Ultimately, addressing these multifaceted challenges are essential for preventing and controlling influenza outbreaks and safeguarding the health and well-being of populations worldwide [122].

## Current Landscape of Avian Influenza Virus in Colombia

Colombia is situated in a region known for its rich avian biodiversity and agricultural importance at the crossroads of South and Central America. Colombia faces unique challenges in mitigating the spread of avian influenza and preventing outbreaks among poultry populations. Despite efforts to monitor and control the spread of the disease, avian influenza remains a persistent threat in Colombia. In this country, the presence of avian IAV has been documented in both wild bird populations and domestic poultry [123–125]. Colombia's varied ecosystems offer habitats for numerous bird species, including migratory birds [126] that could act as carriers for transmitting IAV.

Migratory bird routes in the Americas, known as flyways, are critical pathways that many avian species follow during their seasonal migrations between breeding and wintering grounds [127]. These routes stretch from North America to South America, passing through key areas such as Colombia. Colombia plays a crucial role in these migrations due to its location in the heart of the continent and its diverse ecosystems, which provide essential stopover sites for birds to rest and refuel (Fig. 3). However, as seen in other locations, the movement of large numbers of birds through the region also increases the risk of disease transmission, particularly avian influenza [128]. The migratory birds can spread avian influenza viruses along their flyways, as seen recently, beginning 2024, when an important outbreak of avian influenza affecting wild bird species and poultry occurred in several latin american countries, including Colombia [72] (Fig. 3).

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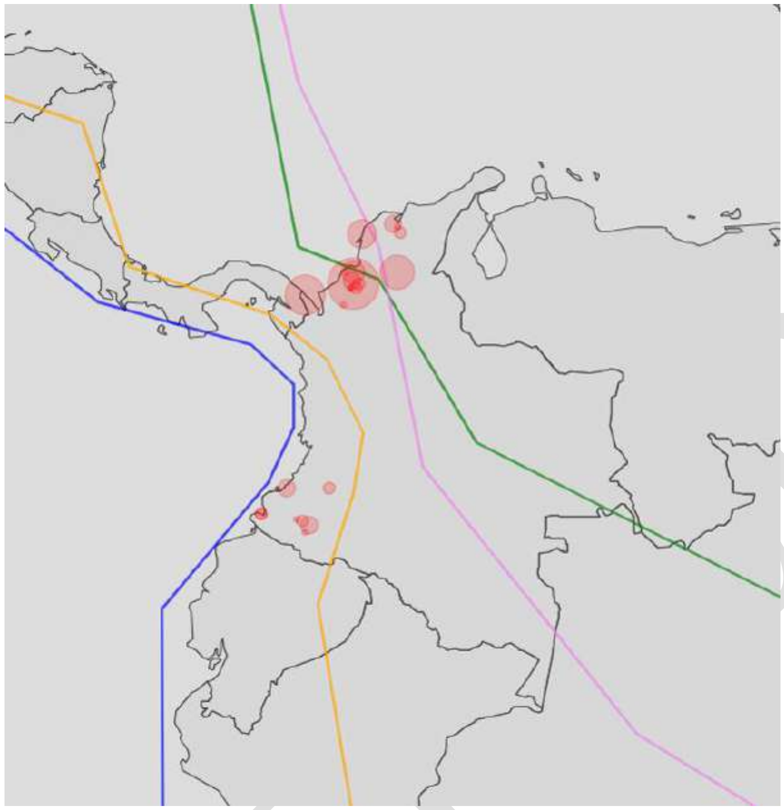

**Figure 3.** Map showing the location of the avian influenza outbreaks confirmed in Colombia during 2022-2024. The figure also illustrates the migratory flyways followed every year by austral and boreal migratory birds species. Red circles indicate the number of outbreaks reported in backyard poultry and wild birds. Pacific flyway (blue), Central flyway (yellow), Austral flyway (violet), Mississippi and Atlantic flyways (green). Created using Openstreet maps (Leaflet package) and R software v.4.4.1.

Additionally, Colombia's poultry industry, although smaller in scale than some other countries, plays a crucial role in domestic food production and rural livelihoods [129,130]. Colombia is the fourth largest broiler and egg producer in Latin America [131]. Also, backyard poultry represent an important source of food security for rural communities in latin American countries such as Colombia [132–134]. In 2013, H5N2 viruses were isolated from resident species of whistling ducks (*Dendrocygna* genus) in the Llanos region of Colombia. These viruses were similar to wild bird viruses from North America, and exhibited low pathogenicity in chickens and mammals.

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However, these findings within a small area of Colombia underscored the need of an impproved monitoring of animal influenza across regions in the country, including the potential transmission of low-pathogenic H5N2 viruses from wild birds to domestic poultry and the emergence of reassortant viruses in domestic swine [123]. Live animal markets play a crucial role in providing food and supporting trade in many countries, but they also have the potential to act as hubs for the emergence and transmission of avian influenza viruses [135,136]. In 2015, Avian H11 influenza virus were isolated from domestic poultry in a live animal market located in the northern region of the Colombia. In this study, the genetic similarity of the Colombian H11 viruses to North and South American shorebirds strains suggested that the occurrence may have been the result of a spillover event from wild birds to domestic poultry [124]. In addition, between 2022 and February 2024, Colombia experienced a rise in avian influenza outbreaks, reporting a total of 66 cases. Of these, 60 occurred in backyard poultry, while 6 were detected in wild bird populations, along with 740 reported alerts or notifications [72,137]. Stringent biosecurity measures within the poultry industry managed to keep the virus out of commercial production. This situation showed the highly potential economic and social impact of the spread of the HPAI virus in this country, trigerring and forcing private and public sectors to work on regulatory frameworks and guidelines for implementing a national vaccination program against avian influenza in poultry [138].

Several factors contribute to the risk of avian IAV outbreaks in Colombia. The country's geographical location makes it susceptible to introducing avian IAV through migratory bird routes and trade activities. Domestic poultry production ranges from high biosecurity commercial farms to backyard poly-culture farming, where domestic poultry often come into contact with wild birds [139]. Furthermore, the movement and mixing of domestic poultry to live poultry markets, where multiple species are usually housed together regardless of origin, enhance the spread and mixing of IAVs [124,136,140]. Socio-economic factors such as limited biosecurity measures in informal poultry production systems increase the likelihood of virus transmission within domestic poultry populations [70].

To address the threat of avian IAV, Colombia should enforce and implement robust surveillance and control measures aimed at early detection and containment of outbreaks. These efforts may include regular monitoring of poultry farms, wild birds, and backyard animals for rapid response

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protocols when suspected cases in high-risk areas are detected. Furthermore, it is crucial to collaborate with international organizations and neighboring countries to exchange information and coordinate responses to avian IAV threats. Despite these efforts, challenges remain for effectively managing avian IAV in Colombia. Limited resources and infrastructure pose barriers to comprehensive surveillance and control measures for infectious diseases [141–144]. Furthermore, the emergence of HPAI strains with zoonotic potential underscores the need for ongoing vigilance and preparedness in the face of evolving influenza threats. Moving forward, a multidisciplinary approach that integrates veterinary, public health and environmental expertise is essential for addressing the complex challenges posed by avian IAV in Colombia. By enhancing surveillance systems, improving biosecurity practices, and promoting collaboration across sectors, Colombia can better protect both animal and human populations from the impacts of avian influenza.

**One Health Approach to Avian Influenza Management**

Avian influenza presents a complex challenge at the intersection of human, animal, and environmental health. The One Health (OH) approach recognizes the interconnectedness of these domains and emphasizes collaborative efforts to address health threats that transcend species boundaries [145]. In the context of avian IAV management, the OH approach is paramount, as the virus can potentially infect various avian and mammalian species, including humans. This approach integrates expertise from diverse disciplines, including veterinary medicine, public health, ecology, epidemiology, and social sciences [146]. Influenza outbreaks in Asia prompted the adoption of the OH approach [147–149]. Evaluation and ongoing surveillance of poultry systems and investigations at the animal-human interface identified human exposure routes and viral persistence factors [150]. Epidemiological studies and molecular analysis revealed the role of live poultry markets and interventions in interrupting transmission [151]. Enhanced biosecurity and vaccination prevented further human H5N1 cases and reduced poultry outbreaks [152]. Similar strategies aided in understanding and preventing other disease outbreaks [122]. Therefore, the OH approach was practical to identify pathways for zoonotic transmission in different epidemiological scenarios, understand the genetic evolution of the virus, and highlight the need for early detection improvement of proper biosecurity practices and awareness among the poultry raisers, traders, and consumers [149,153]. By fostering interdisciplinary collaboration, the OH approach allows for a

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more thorough comprehension of the factors that impact avian IAV transmission, spread, and impact. One key aspect of this approach is surveillance. Surveillance systems that monitor avian IAV in animal and human populations are essential for early detection of outbreaks and timely response efforts [154]. Veterinary surveillance in poultry farms' backyards and wild bird populations can provide valuable data on virus circulation [114]. In contrast, human surveillance helps identify cases of zoonotic transmission and monitor for potential pandemic strains [155]. In addition to surveillance, prevention and control measures are critical. Even though vaccination has not yet been officially implemented in avian and swine species in Colombia, strict biosecurity measures on poultry farms and improved prevention in backyard systems will reduce the risk of virus introduction, transmission, and spread [156]. Also, in this scenario, promoting vaccination in human and animal populations is key [157]. Educating stakeholders about safe handling practices and the risks associated with avian IAV is highly recommended [158].

Furthermore, the OH approach recognizes the role of environmental factors in avian IAV transmission. Environmental surveillance, which involves monitoring water sources and ecosystems for the presence of avian IAV viruses, can also provide valuable insights into the ecological drivers of virus circulation and inform targeted intervention strategies [159,160]. Climate change patterns seem to relate to the global spread of HPAI, causing mass mortalities in previously unaffected bird species posing threats to agriculture and human health due to mutations and sustained presence in poultry systems [161]. The introduction of HPAI H5 clade (2.3.4.4b) viruses into the Americas in 2021–2022 marked unprecedented expansion in the geography and impact of HPAI [162]. Anthropogenic climate change may intensify HPAI dynamics in wild birds through temperature shifts, extreme weather events, and alterations in bird behavior and disease risks [163,164]. Advancing HPAI research in this climate change era demands interdisciplinary and international collaboration [165]. Studying host ecology, virus dynamics, and anthropogenic-climate interactions at various scales poses integration challenges [164]. International collaboration is also vital to the OH approach to infectious disease management [166]. Given the global nature of avian IAV, coordinated efforts between countries are essential for sharing information, resources, and best practices [167]. Collaborative research initiatives, capacity-building programs, and cross-border surveillance networks will strengthen global preparedness and response to infectious disease threats [168].

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In Colombia, several studies have shown the circulation of animal influenza viruses in several populations [72,123,124,144,169,170], but few of them have focused on exploring the interspecies transmission patterns. However, the fact that swine and poultry populations, horses, as well as wild birds species have been reported infected by IAV in this country, as well as experiences observed in other countries regarding interspecies transmission patterns, and the effect of globalization, climate, and other, emphasizes the need of collaborative efforts between disciplines to address IAV from a wider approach.

The OH approach should also involve the creation of a collaborative framework that emphasizes the roles and synergies between national entities like agricultural authorities and the Ministry of Health, alongside universities [171]. International organizations (World Health Organization, Food and Agriculture Organization of the United Nations, United Nations Environment Programme and World Organisation for Animal Health) have provided a framework for integrating human, animal, and environmental health sectors to collaboratively address health challenges such as zoonotic diseases, antimicrobial resistance, and ecosystem health [172]. Within this framework, each entity contributes to infectious disease surveillance, prevention, and response at different levels (Fig. 4). The Ministry of Health would lead in monitoring human health impacts, while agricultural authorities would oversee animal health and biosecurity measures. Universities, as research hubs, would be central to generating scientific knowledge, developing diagnostic tools, and training future experts in zoonotic diseases. This integration would foster a more coordinated effort to combat zoonoses like avian influenza, with universities playing a key role in translating research into policy and actionable strategies.

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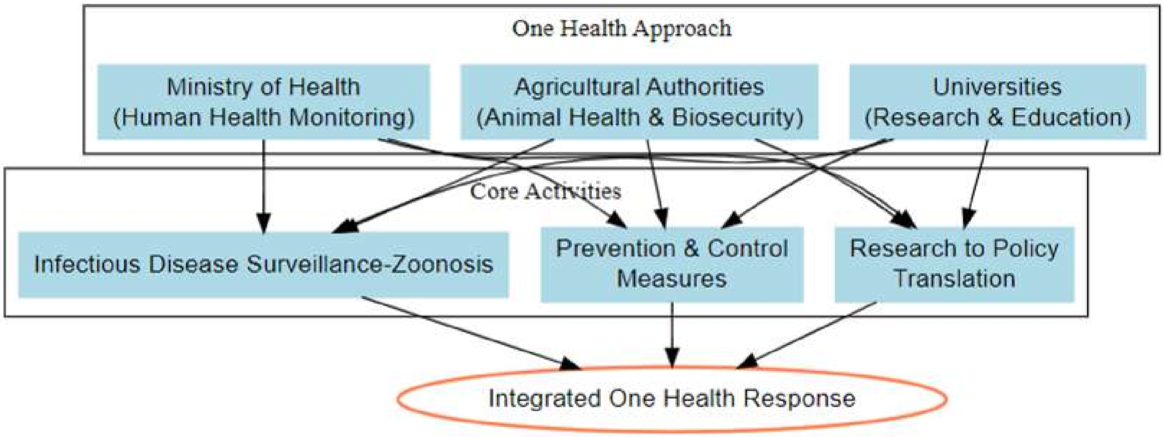


**Figure 4.** One Health Framework showing relatioships and contributions at different levels of entities and key stakeholders to infectious disease surveillance, prevention, and response.

## Bridging Gaps

Effective IAV surveillance and rapid response are critical for Animal influenza control efforts [173]. In Colombia, enhancing surveillance systems and response strategies is essential for early detection and containment of bird influenza outbreaks. By leveraging innovative surveillance tools, strengthening laboratory capacity, and improving coordination among stakeholders, the country can enhance the ability to detect, monitor, and respond to avian influenza threats [148]. While Colombia has made strides in monitoring and controlling avian influenza outbreaks, significant gaps remain in its surveillance and response mechanisms. These gaps challenge early detection, effective containment, and preventing bird influenza from spreading within the country [114]. Despite the implementation of surveillance programs, coverage in certain regions of Colombia may be limited or sporadic. Remote and rural areas, where small-scale and backyard poultry farming is prevalent, often lack sufficient surveillance infrastructure and resources [174]. As a result, avian influenza outbreaks in these areas may go undetected or underreported, delaying response efforts and allowing the virus to spread unchecked. The ability to rapidly and accurately diagnose avian influenza infections is crucial for effective surveillance and response [175]. However, Colombia may face challenges in terms of diagnostic capacity, including access to reliable diagnostic tests, trained personnel, and laboratory facilities equipped to handle avian influenza testing. Delays or inaccuracies in diagnosis can hamper timely intervention measures and exacerbate the risk of transmission of avian flu.

Effective surveillance and response to avian influenza require strong coordination and communication among various stakeholders, including government agencies, veterinary and public health authorities, poultry producers, and international partners [176]. In Colombia, gaps in coordination and communication may hinder the timely sharing of information, coordination of response activities, and dissemination of guidance and recommendations to relevant stakeholders. Also, while biosecurity measures are critical for preventing avian influenza introduction and spread, their implementation and enforcement may be inconsistent across production systems and backyard settings as seen in some studies [67,68,177]. This scenario may be occurring also in Colombia. Limited awareness, resources, and technical support for animal producers may contribute to gaps in biosecurity practices, increasing the risk of avian influenza transmission within and between animal populations [178].

Furthermore, wild birds serve as natural reservoirs and potential vectors for avian influenza transmission, highlighting the importance of surveillance in these populations [179]. However, surveilling wild bird populations can be challenging due to logistical constraints, including accessing remote habitats and capturing and testing birds. As a result, surveillance efforts may overlook potential sources of avian influenza introduction and spread. Molecular epidemiology, based on genomic surveillance, plays an increasingly important role in monitoring IAV, especially in those that cause sporadic zoonotic disease and which may represent a potential risk of future influenza pandemics [3]. Technological advances have allowed for the fast sequencing of whole viral genomes, and genomic sequences of IAV can be examined to monitor the spread and development of outbreaks [3]. Also, molecular epidemiology tools have been applied to determine the origin of pandemic viruses and understand what made them successful pathogens. An excellent example is the recent phylogenetic genome analysis of the 1918 pandemic IAV [180]. Other examples include applying these molecular methods to investigate the recent outbreaks of avian H5N1 and H9N2 influenza viruses [181–183]. Although many questions remain, advances in genomic surveillance over the past two decades have demonstrated its utility in defining viral agents' genetic constitution and molecular structure [184]. Therefore, understanding and addressing these shortcomings is essential for enhancing Colombia's capacity to manage avian influenza and mitigate its impact on public health and agricultural sectors.

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## Identifying Hotspots and Vulnerable Regions in Colombia

Avian influenza outbreaks in Colombia exhibit a varied geographical distribution influenced by ecological, environmental, and socioeconomic factors. Identifying these hotspots and vulnerable regions is crucial for prioritizing surveillance and efforts to control the spread of the virus and reduce its impact on poultry and public health. Information about the epidemiology of avian IAV in Colombia is minimal, mainly due to the lack of robust animal influenza surveillance programs. The latest HPAI H5N1 avian IAV outbreaks were documented in at least 17 countries across Latin America incluiding Colombia [185]. Bird migrations have been historically correlated with outbreaks of HPAI, showing a notable concentration in some specific wild bird migratory pathways [27,186]. In Colombia, HPAI H5N1 outbreaks primarily affected backyard poultry, with a smaller number affecting wild bird populations. Cases were reported in regions including Córdoba, Chocó, Cartagena, Sucre, Magdalena, Nariño, and Cauca, indicating a widespread virus distribution across the country [138,187]. Efforts to contain the spread of these HPAI outbreaks in the country were significant. Fortunately, no human cases of infection with avian influenza were reported in connection with the registered outbreaks. However, since 2013 researchers made recommendations on strengthening animal influenza surveillance in this country based on identification of important IAV with potential impact to animal and publich health [123,124,144]. Thus, continued surveillance and collaboration between public health authorities, veterinary agencies, academy and local communities are essential to prevent further transmission and mitigate the risk of zoonotic transmission to humans.

Nearly 300 species of wild birds, representing vast populations, migrate between the Neotropics and North America [188]. These Nearctic-Neotropical migrants rely on several stopover sites along their migratory path for essential resources like fuel, safe roosting spots, and emergency shelters [189]. Central America's geography and northern Colombia are concentrated areas, funneling millions of birds through critical stopover sites [190]. Additionally, these regions present challenges with barriers like the Caribbean Sea and the Gulf of Mexico, necessitating stopover locations for birds to refuel safely [191]. Colombia's unique position in South America, with coastal marine territories, is crucial for several bird groups, with three significant flyways identified for Neotropical migrants [192]. Colombia's significance in the context of avian influenza

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lies in its privileged position along major migratory routes for several migratory bird groups. These migratory pathways could potentially facilitate the spread of avian influenza viruses between locations, making countries, like Colombia, a critical focal point for surveillance and monitoring efforts to detect and prevent the transmission of bird influenza among animal populations [112].

To date, the few reports of avian influenza cases in Colombia may reveal that higher bird influenza outbreaks occur more consistently in certain regions than others. These hotspots may coincide with areas characterized by stopover areas for migratory birds, intensive poultry production, dense poultry populations, and/or high poultry trade and movement levels. Departments such as Cundinamarca, Santander, and Valle del Cauca may be more severely affected by avian influenza outbreaks due to their significant poultry farming activities and proximity to major urban centers. In addition to human activities and poultry production practices, ecological risk factors may significantly shape Colombia's geographical distribution of avian influenza cases. Environmental factors such as proximity to wetlands and water bodies, which serve as natural habitats for wild bird populations and potential reservoirs for avian influenza viruses, contribute to the transmission dynamics of the virus [193]. Regions with high concentrations of migratory bird habitats and bird migration routes may experience increased transmission of avian flu risk due to the interaction between wild and domestic bird populations [42]. Identifying potential hotspots and vulnerable regions for avian influenza outbreaks involves a comprehensive assessment of epidemiological and ecological factors [194]. Geographic Information Systems mapping and spatial analysis techniques can help visualize and analyze avian influenza surveillance data concerning environmental variables, enabling the identification of high-risk areas and disease transmission patterns [195].

Prioritizing surveillance and control measures in avian influenza hotspots and vulnerable regions is essential for effectively managing avian flu in Colombia. Targeted surveillance efforts, including increased sampling and testing of poultry and wild bird populations in high-risk areas, can enhance early detection and response capabilities, enabling prompt intervention to prevent further virus spread [196]. Furthermore, implementing biosecurity measures, vaccination campaigns, and public awareness initiatives tailored to specific geographical regions can help mitigate the risk of avian influenza outbreaks and protect both animal and human health [74]. By

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leveraging epidemiological data and ecological risk factors to identify and prioritize avian influenza hotspots and vulnerable regions, countries like Colombia can strengthen its surveillance and control strategies, ultimately reducing the burden of bird influenza on the poultry industry and safeguarding public health [43,175]. Implementing new technologies, along with continued monitoring and adaptive management approaches are essential for effectively addressing the dynamic nature of avian influenza transmission [175] and ensuring the resilience of Colombia's poultry sector in the face of emerging infectious disease threats.

**Strategies for Intervention and Prevention**

In Colombia's fight against avian influenza, a multifaceted approach incorporating intervention and prevention measures is essential to mitigate the disease risk on poultry populations and public health. Implementing vaccination campaigns, biosecurity protocols, and public awareness campaigns can significantly reduce the spread of avian influenza and limit its impact on agricultural productivity and human health [74].

Vaccination of poultry populations against IAV is a crucial preventive measure to minimize disease transmission risk and reduce outbreaks' severity [197]. In Colombia, targeted vaccination campaigns can be implemented in high-risk areas, such as regions with a history of avian influenza outbreaks or where large poultry populations are concentrated. Vaccinating susceptible birds, such as chickens and turkeys, against prevalent avian influenza strains can significantly reduce the likelihood of virus transmission within poultry flocks [197]. Furthermore, vaccination can also help protect human health by decreasing the risk of zoonotic transmission of avian influenza viruses from infected poultry to humans [198].

Improving biosecurity measures on poultry farms and in backyard poultry settings is vital for preventing the introduction and spread of avian influenza viruses [156,199]. Biosecurity protocols should include restricting access to production facilities, implementing strict hygiene practices, and maintaining clean and sanitized equipment. Additionally, separating poultry from wild birds and other animals, such as swine, controlling the movement of people and vehicles, and ensuring proper disposal of poultry waste are essential components of effective biosecurity measures [70]. Training and educating farmers and workers on the importance of biosecurity and providing them

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with the necessary resources and support to implement these measures are critical for their success [200].

Public awareness campaigns aimed at poultry producers (especially backyard), workers, and consumers can help increase knowledge and understanding of avian influenza and promote the adoption of preventive measures [158]. These campaigns can utilize various communication channels, including television, radio, social media, and community outreach programs, to disseminate information about the risks associated with avian influenza, the importance of vaccination and biosecurity, and the signs and symptoms of avian flu infection in animals and humans. Public awareness campaigns can empower individuals and communities to proactively prevent avian influenza outbreaks and protect their health and livelihoods by raising awareness and promoting behavioral changes [201].

**Integrating Avian Influenza Considerations into Public Health Policies**

Integrating avian influenza considerations into public health policies is essential for effectively managing the risks associated with avian influenza outbreaks and safeguarding animal and human health [202,203]. As avian flu poses a significant threat to poultry populations and can potentially cause zoonotic infections in humans, addressing this public health challenge requires a coordinated and proactive approach at the policy level [48]. By incorporating avian influenza considerations into public health policies, Colombia can enhance its capacity to prevent, detect, and respond to avian influenza outbreaks, mitigate the impact of the disease on agricultural productivity and public health, and strengthen its overall preparedness and resilience to emerging infectious diseases.

While integrating avian influenza considerations into public health policies offers numerous benefits, there are challenges and opportunities associated with policy implementation in Colombia. One of the main challenges facing policy implementation is the limited resources and infrastructure available for disease surveillance, prevention, and control efforts in Colombia. As seen in other similar countries, insufficient funding, inadequate laboratory capacity, and a shortage of trained personnel may hinder the effective implementation of avian influenza policies and programs [204]. To overcome these challenges, Colombia must prioritize investments in infectious

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disease surveillance systems, laboratory infrastructure, and workforce development to strengthen its capacity to detect and respond to avian influenza outbreaks and other emerging threats. Also, effective policy implementation requires coordination and collaboration among multiple stakeholders, including government agencies, veterinary and public health authorities, poultry producers, and international partners [205]. However, achieving consensus and cooperation among diverse stakeholders may be challenging due to competing priorities, conflicting interests, and limited communication channels [206]. Colombia can establish multi-sectoral task forces, interagency working groups, and public-private partnerships to facilitate information sharing, resource mobilization, and joint decision-making to enhance coordination and collaboration.

In addition, developing and enforcing regulatory frameworks for avian influenza control and prevention can be complex and challenging [205,207]. In Colombia, ensuring compliance with biosecurity measures, vaccination requirements, and reporting protocols may require strengthened regulatory enforcement mechanisms, enhanced monitoring and surveillance systems, and increased penalties for non-compliance, as seen in other countries [208]. Moreover, engaging with local communities and stakeholders to raise awareness about the importance of avian influenza regulations and incentivize compliance can help promote voluntary adherence to regulatory requirements [67]. Furthermore, effective communication and public engagement are essential for building trust, fostering cooperation, and encouraging behavior change among stakeholders and the general public [209]. However, communicating complex scientific information about avian influenza risks and preventive measures in a clear, accessible, and culturally sensitive manner can be challenging [207]. Colombia, as reported in other countries, can leverage traditional and digital media channels, community outreach programs, and public awareness campaigns to disseminate avian influenza-related information, address misconceptions, and engage stakeholders in dialogue and decision-making processes [210].

**Strategies for the establishment of Influenza early monitoring and prevention programs in Colombia.**

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Like other tropical and middle income countries, Colombia faces several challenges to improve the early monitoring and prevention of avian influenza outbreaks. Vaccination campaigns, enforced biosecurity protocols, and public awareness campaigns are valuable tools for mitigating the burden of avian influenza worldwide [66,68,201,211]. By integrating these intervention and prevention measures into a coordinated and adaptive strategy, countries such Colombia, could strengthen its capacity to prevent, detect, and respond to avian influenza outbreaks, ultimately safeguarding poultry populations and public health. However, these measures require the allocation of considerable amount of resources and also the political/governmental willingness of the decision makers in the country [148]. In addition, the implementation of such measures and their effectiveness depends on a sustained investment, and ongoing monitoring and evaluation of these programs. Nevertheless, based on some experiences reported in other locations, here are some recommendations that can be applied in the context of Colombia:

**Developing of Early Detection Systems**

- **Community-Based Monitoring**: Training local farmers and community members to identify symptoms of avian flu in birds [212]. Provide basic training in bird health and data collection using mobile apps or local reporting centers to ensure real-time monitoring.
- **Rapid Diagnostic Kits**: Introducing affordable and easy-to-use diagnostic kits for early detection of avian flu in remote areas [213]. These kits can be distributed to community health centers, poultry farmers, and wildlife observers (i.e. natural parks or protected natural areas) for quick and reliable results.
- **Mobile Surveillance Teams**: Establishing mobile veterinary teams that can visit backyard poultry farms in rural areas to collect samples and assess the health of bird populations [214]. These teams could be organized by government agencies or through partnerships with universities and NGOs.
- **Partnership with Universities and Research Centers**: Leverage the expertise of academic institutions to design real-time data analytics systems that track bird movement patterns, environmental factors, and symptoms of avian flu [215,216]. They can also contribute to conducting field tests for avian flu detection.

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**Vaccination Programs**

- **Targeted Vaccination Campaigns**: Prioritizing high-risk areas based on previous outbreaks, bird migration routes, and areas with dense backyard poultry populations [217]. Working with local governments to map out these regions and schedule regular vaccination campaigns.
- **Subsidized or Free Vaccines**: Provision of government-funded vaccines to small-scale farmers and backyard poultry keepers [67]. To ensure the participation of low-income communities, offer vaccines either for free or at a subsidized rate.
- **Mobile Vaccination Clinics**: In rural areas, mobile veterinary units could travel to high-risk regions, conducting vaccination drives [218]. This approach could ensure access to hard-to-reach populations and offer educational outreach on maintaining healthy flocks.

**Biosecurity and Public Awareness**

- **Educational Workshops**: Public instittutions whould offer training workshops for stakeholders [116] and poultry farmers, particularly those in backyard settings [199,219], on the importance of biosecurity measures, such as controlling bird movement, sanitation practices, and isolating sick birds.
- **Awareness Campaigns**: Use radio, television, and social media to educate farmers and stakeholders about the signs of avian flu, how to report outbreaks, and where to access vaccines or testing services. This could help in building trust and increasing program adoption in rural communities [148,155,176,201].

## Conclusions

As in other locations, the examination of avian influenza in Colombia highlights the urgent need for a robust, collaborative approach to managing the virus, integrating human, animal, and environmental health through a One Health framework. Avian influenza poses significant threats to public health and agricultural sectors, with its zoonotic potential and impact on the poultry industry, which is vital for food security and rural livelihoods. Factors such as migratory bird patterns, climate change, and inconsistent biosecurity measures across commercial and backyard poultry farms exacerbate the risks of transmission. Given Colombia's location along major migratory routes, international cooperation is crucial to monitor avian migration and prevent cross-border transmission. To mitigate outbreak risks, key strategies include strengthening surveillance,

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enhancing biosecurity practices, and targeting interventions in identified hotspots and vulnerable regions. Public health policies should prioritize avian influenza considerations, implementing proactive vaccination programs, early detection systems, and community engagement to protect both animal and human populations. By advancing multisectoral collaboration and aligning with global efforts, Colombia can improve its capacity to prevent and control avian influenza, reducing its socio-economic and health impacts.

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