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Poultry-associated zoonotic diseases in the era of climate change and antimicrobial resistance: A One Health perspective

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Abstract

Poultry-associated zoonotic diseases remain major threats to public health, food security, and the sustainability of the poultry industry worldwide. Climate change and the increasing prevalence and spread of antimicrobial resistance have made controlling and managing these diseases more complex than ever. Poultry production sits at the intersection of human, animal, and environmental health. This review examines the major poultry-associated zoonotic diseases and their transmission routes between humans, animals, and the environment. In addition, the effects of climate change on the epidemiology, emergence, and re-emergence of zoonotic diseases are reviewed, along with the relationship between poultry production, antimicrobial resistance, and the dissemination of resistance genes. The roles of biosecurity, food safety, integrated surveillance, and intersectoral collaboration as key disease control strategies are also discussed. This review highlights that sustainable control of poultry-associated zoonotic diseases cannot be achieved by treatment, vaccination, or farm-level biosecurity alone. Achieving effective control requires integrating biosecurity, food safety, responsible use of antimicrobial agents, proper management of poultry waste, integrated surveillance of pathogens and antimicrobial resistance, environmental protection, and wildlife surveillance within a coordinated strategy. Strengthening intersectoral collaboration, evidence-based policy development, investment in research, education, and integrated surveillance systems are essential for managing these global threats. By linking human health, animal health, and environmental health, the One Health approach provides a comprehensive and sustainable framework to reduce the risk of zoonotic diseases, curb antimicrobial resistance, strengthen food security, and enhance the resilience of the poultry industry to future challenges.

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Introduction

Poultry production is characterized by high feed conversion efficiency, rapid growth, and a short rearing period. This industry plays a crucial role in ensuring food security, addressing the nutritional needs of the world's expanding population, and alleviating poverty (1). Chicken meat and eggs are among the most economical and accessible sources of animal protein, offering high nutritional value. Furthermore, poultry production demands

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fewer resources, such as water and land, compared to other livestock production systems, and it generally has a lower environmental footprint (2, 3). The substantial increase in the global population has markedly increased the demand for poultry products, thereby fostering the expansion of the poultry sector. The growth of the poultry industry is pivotal for job creation, rural economic development, and international trade (1). Sustainable poultry farming represents a crucial solution to future food security challenges. Achieving long-term sustainable growth necessitates production systems that are ecologically, socially, and economically responsible, alongside enhanced consumer awareness and sustainable food choices (1, 4). The growth of poultry production systems has increased the risk of emergence and spread of infectious and zoonotic diseases. Infectious diseases are a major concern for the poultry industry. Climate change, increasing pressure on natural resources, and antimicrobial resistance are among the most significant future challenges for the poultry industry (5). As a result, preserving the poultry industry's sustainability requires the implementation of innovative health, biosecurity, and sustainable management solutions, as well as the One Health approach (6, 7).

Poultry as an interface between humans, animals, and the environment

Human–Poultry Interactions

Poultry production lies at the intersection of human, animal, and environmental health, making it a key component of the One Health concept. Human, animal, and environmental health are closely interconnected. Infectious diseases occur and spread at the intersection of these three domains (7). International trade in live poultry, poultry products, and feed, has also contributed to the cross-border spread of infectious diseases. The intensification of industrial production and increased flock density have increased contact among humans, poultry, and the environment, raising the risk of disease transmission, virus mutation, and the emergence of new strains (8, 9). Emerging infectious diseases are mainly of animal origin, emerging in animal populations before spilling over into humans (6). Pathogens proliferate and spread more quickly in high-density animal production environments. The environment heavily influences pathogen survival and transmission. Manure, water, soil, and air can serve as reservoirs and pathways for pathogens (9).

Traditional food markets bring humans, animals, and the environment into close contact. Close contact between humans and live animals increases the risk of zoonotic pathogen transmission. Live bird markets play a significant role in the transmission of avian influenza viruses and other pathogens (10). The presence of many animal species in the same place raises the risk of disease transmission between species. Environmental pollution in markets can continue to spread disease even after the animals have left (11). The food supply chain is an important route for the spread of infectious diseases. Improving biosecurity practices can help minimize disease transmission. Control strategies should consider animal, human, and environmental health. Risk management in traditional markets requires cross-sectoral collaboration and the implementation of a One Health approach (12, 13).

People who work in the poultry production and processing chain, such as veterinarians, poultry farm workers, slaughterhouse workers, meat processing plant workers, live poultry transport drivers, food hygiene inspectors, diagnostic laboratory workers, and live bird market vendors, are at increased risk of zoonotic infection because of their frequent and direct contact with infected birds, carcasses, respiratory secretions, feces, and other products (14, 15). This occupational exposure can result in pathogen transmission through inhalation of contaminated particles and aerosols, direct contact with skin and mucous membranes, injuries from sharp instruments, or contact with contaminated surfaces and equipment (16).

Veterinarians and staff on poultry farms frequently interact with live birds, biological samples, and poultry waste (15). Without adherence to biosecurity measures, they risk exposure to pathogens such as *Salmonella* spp., *Campylobacter* spp., avian influenza viruses, *Chlamydia psittaci*, and pathogenic strains of *Escherichia*

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coli (17). Similarly, workers in slaughterhouses are among the occupational groups at the highest risk of encountering pathogens shared by humans and poultry due to the potential for aerosol formation and contact with blood or the contents of the digestive tract (18).

In addition to the risk of infection among individuals, these occupational groups can act as mechanical vectors of pathogens, causing their transmission between different flocks, the environment, the processing chain, and even society if personal hygiene and biosecurity measures are not observed (19). Therefore, continuous employee training, strict implementation of biosecurity programs, occupational health monitoring, and compliance with occupational health standards are essential elements for reducing the risk of transmission of zoonotic pathogens (7, 20).

Within the framework of the One Health approach, protecting the health of these occupational groups is of fundamental importance, not only for preventing disease in humans but also for maintaining the health of poultry flocks, reducing environmental pollution, and preventing the spread of pathogens in the food production chain. Therefore, veterinarians and farm and slaughterhouse workers are not merely individuals at risk but also play a key role in the success of One Health programs as frontline participants in the surveillance, early detection, reporting, and control of zoonotic diseases (19, 21, 22).

Controlling zoonotic diseases requires more than just implementing biosecurity measures on farms; it requires an integrated strategy that regards human, animal, and environmental health as interlinked components of one system (23). In this context, biosecurity must extend beyond the farm and be supported by integrated systems for monitoring, data exchange, and disease management across all three domains: humans, animals, and the environment (5). Achieving such a goal necessitates close coordination among veterinarians, physicians, public health professionals, environmental health specialists, and epidemiologists within the One Health approach (24).

Poultry-associated zoonotic diseases

Poultry, as one of the most important sources of animal protein, plays an important role in ensuring global food security; however, it can also harbor or transmit a wide range of zoonotic pathogens (7). Major poultry-associated zoonotic pathogens, their transmission routes, and One Health implications are summarized in Table 1. These pathogens are transmitted to humans through direct contact with infected birds, inhalation of contaminated particles and aerosols, consumption of contaminated meat and eggs, contact with manure and poultry waste, and environmental contamination (25, 26). In recent years, the development of intensive poultry farming systems, the expansion of international trade, climate change, increased contact between poultry and wildlife, and the emergence of antimicrobial resistance have increased the importance of zoonotic diseases associated with poultry (4). These diseases can be classified into three main groups: bacterial, viral, and parasitic or fungal diseases (27, 28).

Bacterial zoonoses

Bacteria are among the most important causative agents of poultry-associated zoonoses and foodborne illnesses (Table 1). *Salmonella enterica* is one of the most common causes of human gastroenteritis, which is mainly transmitted through the consumption of contaminated poultry meat and eggs or cross-contamination in the food production chain (28). *Campylobacter jejuni* is also one of the most important causes of bacterial diarrhea worldwide, and broiler chickens are its most important reservoir. Many infected flocks shed this bacterium without showing clinical symptoms, thus playing an important role in its transmission to humans (28, 29).

Among the pathogenic strains of *Escherichia coli*, APEC (avian pathogenic *E. coli*) strains, in addition to causing disease in poultry, are of particular importance from the One Health perspective owing to their genetic similarity to ExPEC (extraintestinal pathogenic *E. coli*) strains in humans and can play a role in the transmission

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of antimicrobial resistance genes (30). *Listeria monocytogenes*, although more commonly associated with ready-to-eat foods, may also transmit this pathogen if contaminated poultry products are consumed (31). In addition, *Chlamydia psittaci* is the causative agent of psittacosis, which can be transmitted to humans mainly through inhalation of contaminated dust or bird droppings and is a significant occupational hazard, especially for veterinarians, poultry farm workers, and slaughterhouse workers (17).

Viral zoonoses

Viruses associated with poultry are among the most important agents of emerging and re-emerging diseases worldwide (Table 1). Avian influenza viruses, especially subtypes H5N1 and H7N9, are among the most important public health threats because of their ability to cause severe disease in humans, their ability to mutate and adapt to new hosts, and their potential for future pandemics (32). Wild waterfowl are natural reservoirs of many influenza A viruses, and transmission of these viruses to domestic poultry can lead to the emergence of highly pathogenic strains (32, 33). Newcastle disease virus is primarily a veterinary pathogen, but in some cases, it can cause mild infections, particularly conjunctivitis, in people in close contact with infected poultry (33). Furthermore, the continued identification of new viruses in poultry and wildlife populations indicates that the poultry industry remains a major source of emerging viral agents; therefore, continuous surveillance of these viruses is of great importance in the One Health framework (34).

Parasitic and fungal zoonoses

Although parasitic and fungal diseases account for a smaller proportion of poultry-associated zoonoses than bacterial and viral pathogens, they remain important public health concerns (Table 1). Some parasites, such as *Toxoplasma gondii*, can be transmitted under certain circumstances through environmental contamination or food products, and some fungi, particularly *Aspergillus* spp., pose a risk to workers and immunocompromised individuals through inhalation of spores in poultry litter and dust. Although direct transmission of many of these agents from poultry to humans is rare, their presence in poultry environments highlights the importance of hygiene, proper litter management, and biosecurity programs (35, 36).

The diversity of pathogens, multiple routes of transmission, the role of wildlife, the spread of antimicrobial resistance, and the impact of climate change on the epidemiology of these diseases suggest that their prevention and control require an integrated approach within the One Health framework; an approach that considers human, animal, and environmental health simultaneously and emphasizes interdisciplinary collaboration, biosecurity, integrated monitoring, and evidence-based management (37, 38).

Climate change as an emerging driver of poultry-associated zoonotic diseases

Climate-related changes in zoonotic disease emergence

Climate change is recognized as one of the most important drivers of the emergence, re-emergence, and spread of infectious diseases in the 21st century, and its effects on human, animal, and environmental health have received increasing attention (16). The complex interactions among climate change, antimicrobial resistance, poultry production, and zoonotic disease emergence are illustrated in Figure 1. Rising global average temperatures, changing precipitation patterns, increased frequency of extreme climate events such as droughts, floods, and storms, and changing ecological conditions have transformed the epidemiology of many zoonotic diseases (39, 40). These changes affect not only the distribution of pathogens but also complicate interactions among humans, animals, and the environment, highlighting the importance of a One Health approach to managing zoonotic diseases (7, 12, 24).

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Table 1. Major poultry-associated zoonotic pathogens, their transmission routes, effects on human health, and One Health significance.

Pathogen	Major poultry reservoirs/sources	Main routes of transmission to humans	Human health effects	One Health significance	Key control measures
Salmonella enterica	Broilers, layers, contaminated feed, and the poultry environment	Consumption of contaminated poultry meat and eggs; cross-contamination during food preparation; direct contact with infected birds	Gastroenteritis, systemic infections in vulnerable individuals	Important foodborne zoonosis; antimicrobial resistance and contamination of the food chain require integrated surveillance	Vaccination; biosecurity; hygiene; safe cooking
Campylobacter jejuni	Broiler chickens (major reservoir), poultry carcasses	Consumption of undercooked poultry meat; cross-contamination; direct contact with birds	Acute diarrhea, enteritis, post-infectious complications	A major global foodborne pathogen; control requires farm-level biosecurity, processing hygiene, and AMR monitoring	Biosecurity, hygiene, flock colonization control, safe processing, and cooking
Avian pathogenic *Escherichia coli* (APEC)	The respiratory and intestinal tracts of poultry	Direct contact with infected birds; contaminated environments and poultry products	Potential contribution to extraintestinal pathogenic *E. coli* infections in humans	Genetic similarity between APEC and human ExPEC strains highlights zoonotic potential and AMR gene transmission	Biosecurity, hygiene, prudent antimicrobial use, vaccination, and AMR surveillance
Listeria monocytogenes	Poultry products, processing environments, contaminated food	Consumption of contaminated poultry products	Listeriosis, which can cause severe disease in pregnant women, older adults, and immunocompromised individuals	Demonstrates the importance of food safety, processing hygiene, and environmental control	Hygiene, sanitation, cross-contamination control, safe processing, and refrigeration
Chlamydia psittaci	Birds, particularly psittacine and other domestic birds	Inhalation of contaminated dust, aerosols, and bird droppings; occupational exposure	Psittacosis, respiratory disease, pneumonia	Important occupational zoonosis affecting veterinarians, poultry workers, and slaughterhouse employees	Biosecurity, hygienic processing, cross-contamination control, and thorough cooking
Avian influenza viruses (e.g., H5N1, H7N9)	Domestic poultry and wild waterfowl	Direct contact with infected birds; contaminated environments; aerosols	Severe respiratory disease and potential pandemic risk	A major One Health concern due to wildlife reservoirs, viral evolution, and global spread potential	Biosecurity; wildlife control; surveillance
Newcastle disease virus	Domestic poultry and wild birds	Mainly occupational exposure through close contact with infected birds	Usually causes mild illness, including conjunctivitis and influenza-like symptoms in exposed individuals	Requires continuous surveillance due to circulation in poultry and wildlife populations	Vaccination, biosecurity, surveillance, movement control, and disinfection
Toxoplasma gondii	Poultry and contaminated environment (indirect role)	Consumption of contaminated meat; environmental exposure	Toxoplasmosis, severe disease in immunocompromised individuals and fetuses	Highlights the interaction between food safety, environmental contamination, and public health	Environmental hygiene, rodent and cat control, and adequate cooking of meat
Aspergillus spp.	Poultry litter, dust, contaminated farm environments	Inhalation of fungal spores	Respiratory disease, especially in immunocompromised individuals	Demonstrates the importance of litter management, ventilation, and occupational health protection	Ventilation, litter management, fungal contamination control, and occupational protection

Heat stress and host susceptibility

The poultry industry is one of the most vulnerable livestock sectors to climate change impacts. Heat stress is one of the most important direct consequences of rising ambient temperatures in poultry farms, which can cause

significant economic losses by reducing feed consumption, growth, and production, impairing reproductive performance, and increasing mortality (41). In addition, heat stress impairs the innate and acquired immune systems of birds, increasing their susceptibility to infection. Under these conditions, infected birds may shed more pathogens, thereby increasing the risk of disease spread within the flock and transmission to humans (32, 42).

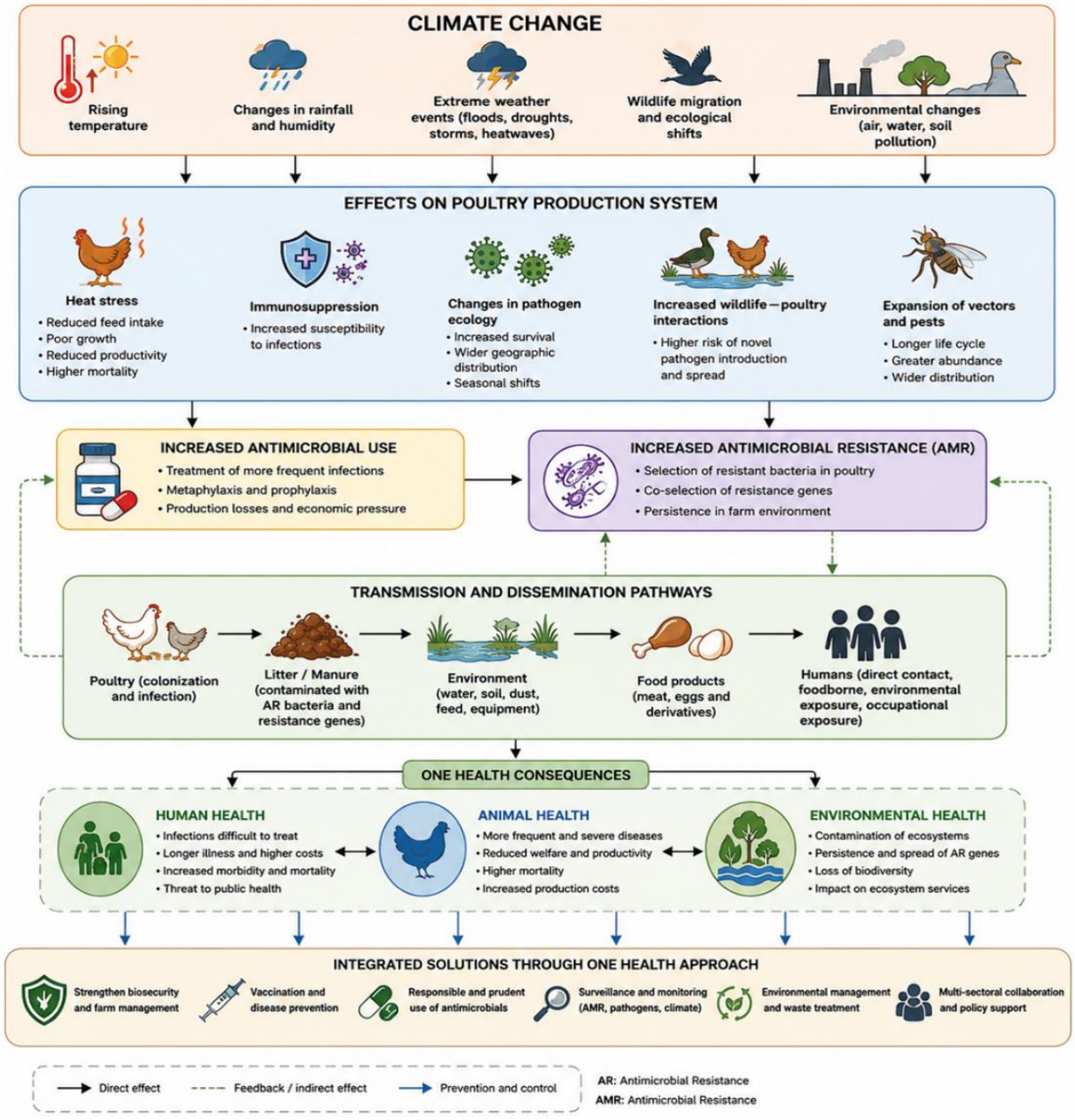


Fig. 1. A One Health framework illustrating the interactions among poultry-associated zoonotic diseases, climate change, antimicrobial resistance, and human, animal, and environmental health (20, 42, 43).

Effects on pathogen transmission and food safety

Climate change also affects the survival, proliferation, and spread of pathogens in the environment. Increased temperatures and changes in humidity can create favorable conditions for the survival and persistence of some foodborne pathogens, such as *Salmonella* and *Campylobacter* (Figure 1). These changes can modify the geographic range of pathogen distribution, the seasonality of disease, the severity of epidemics, and alter traditional patterns of disease outbreaks (43, 44).

Wildlife migration and vector distribution

Another important consequence of climate change is changes in interactions between wildlife and domestic poultry. Changes in bird migration routes, shifting natural habitats, and increased contact between wild birds and poultry farms increase the likelihood of pathogen introduction into domestic herds (Figure 1). Migratory birds are natural reservoirs for many influenza A viruses, and changes in their migration routes or concentrations in shared water sources could increase the risk of transboundary disease transmission and the emergence of new strains (39, 45).

Interaction between Climate Change and AMR

Climate change and antimicrobial resistance (AMR) are among the most important global health challenges of the 21st century (Figure 1). Their interactions have raised new concerns regarding human, animal, and environmental health. Although these two phenomena have often been studied independently, growing evidence suggests that climate change can directly and indirectly affect the patterns of infectious diseases, antimicrobial consumption, and ultimately the spread of antimicrobial resistance (46).

Increasing environmental temperatures, changing rainfall patterns, droughts, floods, and other extreme climatic events can provide more suitable conditions for the survival, proliferation, and spread of many pathogens (39). The increase in disease incidence in livestock populations, particularly in the poultry industry, is often accompanied by increased use of antibiotics to treat or control infections, which increases selective pressure on bacterial populations and accelerates the emergence and spread of resistant strains (46). In addition, climate change can affect the persistence and transmission of resistant bacteria and resistance genes in water, soil, poultry manure, and other environmental components, reinforcing the cycle of antimicrobial resistance (47).

the poultry industry is particularly vulnerable to the combined effects of climate change and antimicrobial resistance to the simultaneous consequences of climate change and antimicrobial resistance (48). Heat stress, reduced immune system efficiency, increased susceptibility to infectious diseases, and changes in pathogen spread patterns increase the likelihood of using antibacterial drugs (41, 42). In contrast, antimicrobial resistance can reduce the effectiveness of antimicrobial treatments, make zoonotic diseases more difficult to control, and pose a serious threat to food security, public health, and the sustainability of poultry production (49).

The interaction between climate change and antimicrobial resistance is not limited to farms but affects the entire food production chain. The spread of resistant bacteria and resistance genes through poultry manure, farm wastewater, water sources, soil, and food products creates a close link between animal, human, and environmental health (50). Therefore, these two challenges must be addressed as interconnected components of a single system, not as independent issues. Given the complexity of these interactions, addressing climate change and antimicrobial resistance simultaneously requires the adoption of comprehensive strategies based on a One Health approach (51). Strengthening biosecurity, responsible use of antimicrobial agents, developing integrated surveillance programs, proper management of poultry waste, improving husbandry conditions, and utilizing early warning systems based on climate data are among the measures that can help reduce the risk of

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pathogen spread and antimicrobial resistance in poultry (49). Understanding the link between these two challenges will pave the way for designing more effective policies to protect public health, maintain food security, and achieve sustainable poultry production in the future (48, 49).

Antimicrobial resistance in poultry production

Current status of antimicrobial use

Antimicrobial resistance (AMR) is one of the greatest global health threats today, and its consequences have affected all aspects of human, animal, and environmental health beyond the boundaries of medicine and veterinary medicine. In the poultry industry, antibiotics have been used for years to treat, control, and prevent bacterial diseases and, in some countries, as growth promoters. Although these drugs have played an important role in maintaining the health of flocks and reducing economic losses, their inappropriate and indiscriminate use has increased selective pressure on bacterial populations and the spread of resistant strains (52).

Mechanisms of AMR emergence

Climate change has also compounded this challenge. Rising temperatures, heat stress, and changing disease patterns can increase the risk of infection in poultry flocks, leading to increased antibiotic use. The emergence of antimicrobial resistance in poultry production is a complex process influenced by biological, management, and environmental factors (52). The use of antimicrobial agents creates selective pressure on bacterial populations, allowing resistant bacteria to survive, multiply, and become dominant within poultry farms. When antibiotics are used frequently or inappropriately, susceptible bacteria are eliminated, while resistant strains have a greater opportunity to persist and spread. This process can occur not only during therapeutic use but also when antibiotics are used without accurate diagnosis, proper dosage, or sufficient treatment duration (53, 54).

Resistance can also spread through the transfer of antimicrobial resistance genes between bacteria (52). Horizontal gene transfer mechanisms, including conjugation, transformation, and transduction, enable bacteria to exchange antimicrobial resistance determinants, even among different bacterial species (53). Mobile genetic elements such as plasmids, transposons, and integrons play an important role in the rapid dissemination of resistance genes among poultry-associated bacteria (52-54). Consequently, bacteria present in poultry farms, slaughterhouses, food products, and the surrounding environment can act as reservoirs and sources for the transmission of antimicrobial resistance genes to other bacterial populations, including those with potential public health importance (52, 54).

Environmental factors also contribute to the persistence and dissemination of antimicrobial resistance. Poultry manure, wastewater, soil, and contaminated water sources may contain antimicrobial-resistant bacteria and antimicrobial resistance genes, allowing their circulation beyond the farm environment (46). Climate-related changes, including increased temperature and extreme weather events, may further influence bacterial survival, environmental dissemination, and patterns of antimicrobial use by increasing disease pressure in poultry populations (48). Therefore, antimicrobial resistance in poultry should be considered not only as a consequence of antibiotic use but also as an ecological challenge involving interactions among poultry, humans, and the environment within the One Health framework (42, 48).

Transmission of resistant bacteria and resistance genes

Resistant bacteria and resistance genes can continuously circulate among poultry, humans, and the environment, spreading through the food chain, direct contact with birds, poultry manure, farm wastewater, and other environmental sources (52, 53). In addition, changing environmental conditions can affect the survival and spread of resistant bacteria and resistance genes in water, soil, and poultry waste, reinforcing the cycle of

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antimicrobial resistance transmission. Therefore, climate change and antimicrobial resistance are two interconnected challenges whose interactions must be considered in disease management programs (52, 54).

Environmental dissemination of AMR

Antimicrobial resistance is therefore a prime example of the interaction among the three main components of the One Health approach, and its control will require consideration of the interrelationships among human, animal, and environmental health (51, 54).

Public health implications

Effectively addressing antimicrobial resistance in the poultry industry requires a set of complementary strategies, including rigorous implementation of biosecurity programs, effective vaccination, improved farm management, responsible and evidence-based use of antibacterial drugs, continuous antimicrobial resistance monitoring, and strengthening integrated surveillance systems (55, 56). Close collaboration among veterinarians, clinicians, public health professionals, environmental scientists, the food industry, and policymakers is also essential to reduce the spread of antimicrobial resistance and maintain the effectiveness of existing drugs (55-57).

Overall, antimicrobial resistance is one of the most important challenges facing the poultry industry and public health in the 21st century (16, 52). Sustainable management of this threat requires the adoption of integrated strategies based on the One Health approach, an approach that, by combining preventive measures in the areas of human, animal, and environmental health, can play an effective role in reducing the spread of resistant bacteria, maintaining food security, and ensuring the sustainability of poultry production in the future (49, 52).

One Health strategies for prevention and control

Effective control of poultry-associated zoonotic diseases requires the implementation of a set of coordinated actions across human, animal, and environmental health (37). Implementing comprehensive biosecurity programs, improving housing and husbandry conditions, controlling the introduction of pathogens into farms, effective vaccination, continuous monitoring of herd health, observing hygiene principles in slaughterhouses and processing plants, and strengthening food safety measures are among the most important measures to reduce the risk of pathogen transmission to humans (37, 57). Proper management of poultry manure, sewage, and other production wastes also plays an important role in reducing environmental pollution and limiting the spread of pathogens and antimicrobial resistance genes. Responsible and evidence-based use of antimicrobial agents is another essential pillar of the One Health approach (49, 58).

Reducing unnecessary antibiotic use, conducting pre-treatment diagnostic tests, implementing medication management programs, developing alternatives such as vaccines, probiotics, prebiotics, and postbiotics, and strengthening antimicrobial resistance surveillance programs can help maintain the effectiveness of existing drugs and reduce the spread of resistant bacterial strains. Integrated disease surveillance also has a special place in this approach (49, 52). The integration of information from veterinary, medical, public health, environmental, and food safety systems allows for the rapid identification of emerging threats, the tracking of disease transmission routes, and a timely response to epidemics (38, 59). The use of new technologies, such as molecular epidemiology, genomic sequencing, geographic information systems, artificial intelligence, and predictive models based on climate data, can significantly increase the accuracy of disease surveillance and control programs (60-63). Given the increasing impact of climate change on disease patterns, One Health strategies must also include climate adaptation (58). Strengthening the resilience of poultry production systems, developing early-warning systems, wildlife monitoring, vector management, and conservation of natural

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resources are among the measures that can reduce the risk of the emergence and re-emergence of zoonotic diseases (39, 64).

The success of One Health strategies is not possible without close collaboration among veterinarians, physicians, public health specialists, environmental experts, the food industry, researchers, poultry industry managers, and policymakers (65-67). Coordinated policy development, data sharing, stakeholder education, raising public awareness, and enhanced national and international collaborations pave the way for more effective management of zoonotic diseases and reduction of their impacts (37, 68). By integrating biosecurity, food safety, environmental management, integrated surveillance, responsible use of antimicrobial agents, intersectoral collaboration, and the application of emerging technologies, the One Health approach provides a comprehensive framework to reduce the risk of zoonotic diseases, contain antimicrobial resistance, improve food security, and achieve sustainable poultry production (69-71). These strategies will be essential to address current challenges and increase preparedness for future threats (52, 57, 70, 71).

Current Challenges

Despite significant advances in biosecurity, vaccination, disease detection, and farm management, zoonotic diseases associated with poultry remain one of the most important threats to public health and the poultry industry worldwide (72-74). The expansion of international trade in poultry and its products, the increasing global demand for poultry products, the development of intensive farming systems, and the increasing interaction between humans, animals, and the environment have created conditions for the emergence, re-emergence, and rapid spread of pathogens (75, 76). In such circumstances, disease control has become a complex and multidimensional challenge (4, 77).

One of the most important challenges ahead is the impact of climate change on the spread patterns of zoonotic diseases (39). Rising global temperatures, changes in precipitation patterns and rates, extreme weather events, and changes in the distribution of wildlife and disease vectors have altered the epidemiology of many pathogens, making them more difficult to predict and control (64). These changes not only increase the risk of emerging diseases but can also reduce the effectiveness of current disease control programs (39). Antimicrobial resistance is another major challenge in the poultry industry and public health (78-80). The inappropriate or excessive use of antimicrobial agents, coupled with the spread of resistant bacteria and resistance genes in humans, animals, and the environment, threatens the effectiveness of existing treatments and poses serious challenges to the control of infectious diseases (81, 82). Simultaneously, the interplay between climate change and antimicrobial resistance has further complicated the management of these two global threats (48, 52).

Furthermore, the implementation of biosecurity and disease surveillance programs in many parts of the world is constrained by a lack of financial resources, weak diagnostic infrastructure, incoherence between surveillance systems, differences in national policies, and a lack of information exchange between the veterinary, medical, and environmental sectors (60). These constraints make it difficult to identify diseases early and to implement effective control measures (37). Another important challenge is the management of risks throughout the food production chain (75, 83). Possible contamination during the breeding, slaughter, processing, transport, distribution, and consumption stages continues to pose a risk of transmitting pathogens to humans (19). In contrast, improper management of poultry manure, sewage, and other production wastes can lead to the release of pathogens and antimicrobial resistance genes into the environment, reinforcing the cycle of disease transmission (29).

In addition, increased contact between poultry, wildlife, and humans, particularly as a result of land use change, agricultural development, urbanization, and climate change, has increased the risk of pathogen transmission and the emergence of diseases (39). Overall, the control of zoonotic diseases associated with poultry in the era of

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climate change and antimicrobial resistance faces multiple interconnected and multifactorial challenges (4). Overcoming these challenges requires strengthening intersectoral collaboration, developing integrated surveillance systems, responsible use of antimicrobial agents, promoting biosecurity, improving food safety, and adopting policies based on the One Health approach (20). Understanding these challenges will pave the way for designing more effective strategies to achieve sustainable poultry production, protect public health, and increase the resilience of food systems against future threats (39, 49).

Future perspectives

Global trends indicate that zoonotic diseases associated with poultry will face more complex challenges in the coming decades, driven by climate change, increasing demand for poultry products, expanding international trade, population growth, land use change, and the rise of antimicrobial resistance. Therefore, traditional disease control strategies alone will not meet future needs, and the development of innovative, preventive, and evidence-based approaches is essential to protect human, animal, and environmental health (4, 64).

A key priority for the future is to strengthen integrated surveillance systems within the One Health framework. The integration of veterinary, medical, environmental, and climate data, together with effective information exchange between responsible institutions, will enable the rapid identification of emerging threats, prediction of disease trends, and timely response to outbreaks. The use of new technologies, such as next-generation sequencing (NGS), genomic epidemiology, metagenomics, geographic information systems (GIS), remote sensing, and AI-based predictive models, can significantly increase the accuracy of disease surveillance and control programs (37, 84, 85).

The development of climate-resilient farming systems is particularly important in poultry production. Improving the design of breeding houses, upgrading ventilation and cooling systems, using more resistant breeds, increasing animal welfare, and optimizing nutritional management and environmental conditions can reduce the effects of heat stress and limit the susceptibility of flocks to infectious diseases (46). Simultaneously, more rigorous implementation of biosecurity programs, wildlife contact management, and vector control must become an integral part of sustainable production programs (8).

Addressing antimicrobial resistance also requires a transformation in flock health management practices (78). Reducing unnecessary antibiotic use, establishing effective drug management programs, developing effective vaccines, and expanding the use of alternative approaches, such as probiotics, prebiotics, postbiotics, phytobiotics, and other bioactive compounds, can reduce the poultry industry's reliance on antimicrobial agents and contribute to curbing antimicrobial resistance (49, 78). However, the future of zoonotic disease control will depend on extensive collaboration among veterinarians, clinicians, environmentalists, epidemiologists, food industry professionals, researchers, and policymakers (60). Developing coordinated policies, strengthening laws related to biosecurity and antimicrobial use, investing in education, developing laboratory infrastructure, and increasing regional and international cooperation will play an important role in increasing countries' preparedness to address emerging threats (86, 87).

Future research should also focus on identifying factors influencing disease emergence, examining the long-term effects of climate change on pathogen ecology, studying the pathways of antimicrobial resistance genes in the environment, developing risk prediction models, and evaluating the effectiveness of One Health interventions (39). Generating scientific evidence in this area can be the basis for more accurate decision-making and more efficient policies at national and international levels. Overall, the future of poultry zoonotic disease management depends on shifting from reactive approaches to preventive, data-driven, and integrated strategies (37). Combining new technologies, integrated surveillance, biosecurity, responsible antimicrobial management, climate change adaptation, and collaboration among all stakeholders can pave the way toward reducing the risk

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of zoonotic diseases, controlling antimicrobial resistance, maintaining food security, and achieving sustainable poultry production (19). In this direction, the One Health approach will be not only a scientific framework but also a practical strategy for promoting global health and increasing the resilience of food production systems to future challenges (4, 48).

Conclusion

Zoonotic diseases associated with poultry continue to be one of the most important threats to public health, food security, and the sustainability of the poultry industry worldwide. Population growth, the development of intensive farming systems, the expansion of global trade in poultry products, climate change, and the growth of antimicrobial resistance have substantially altered the patterns of disease emergence, transmission, and control of these diseases. In such a situation, managing these threats is no longer just a veterinary or medical issue but requires an understanding of the complex interactions between humans, animals, and the environment.

This review highlights the central role of poultry production at the interface of the three main components of the One Health approach and that pathogens, antimicrobial-resistant bacteria, and resistance genes can circulate among these three domains through direct contact, the food chain, wildlife, and the environment. Climate change, by affecting pathogen ecology, heat stress, wildlife migration patterns, environmental quality, and the spread of infectious diseases, has further intensified existing challenges and highlighted the importance of adopting integrated strategies.

The findings of this review show that sustainable control of zoonotic diseases associated with poultry cannot be achieved by treatment, vaccination, or implementation of biosecurity at the farm level alone. Effective control requires a coordinated strategy integrating biosecurity, food safety, responsible use of antimicrobial agents, proper management of poultry waste, integrated surveillance of pathogens and antimicrobial resistance, environmental protection, and wildlife surveillance. Such an approach can reduce the risk of pathogen transmission throughout the production chain, from farm to fork, and improve public health.

The development of new technologies has provided valuable opportunities to enhance prevention and control programs. The use of genomic epidemiology, next-generation sequencing, geographic information systems, artificial intelligence, climate-based predictive models, and early warning systems can enable the rapid identification of emerging threats, more accurate disease surveillance, and evidence-based decision-making. In addition, the development and implementation of effective alternatives to antibiotics and the implementation of antimicrobial stewardship programs will play an important role in reducing antimicrobial resistance.

Ultimately, addressing zoonotic diseases associated with poultry in the era of climate change and antimicrobial resistance requires close collaboration among veterinarians, clinicians, public health professionals, environmentalists, the food industry, researchers, and policymakers. Strengthening intersectoral collaboration, evidence-based policy development, investment in research, education, and integrated surveillance systems are essential for managing these global threats. By linking human, animal, and environmental health, the One Health approach offers a comprehensive and sustainable framework to reduce the risk of zoonotic diseases, curbing antimicrobial resistance, strengthening food security, and enhancing the resilience of the poultry industry to future challenges.

Ethical approval

This review article is based exclusively on previously published literature and publicly available scientific sources. No human participants, animals, or confidential data were involved in this study. Therefore, ethical approval was not required.

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Corrected Proof

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Conflict of interest

The author declares that there are no financial, professional, or personal conflicts of interest that could have influenced the preparation or publication of this review.

Artificial intelligence statement

QuillBot was used solely to improve the language, grammar, and readability of the manuscript. The author critically reviewed and revised all edited text, approved the final version of the manuscript, and takes full responsibility for its scientific content, interpretation, and conclusions.

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