

The impact of zoonotic diseases on the food production chain: A review of key challenges and prevention strategies

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ABSTRACT

Zoonotic diseases pose a major challenge to public health and the safety of food production systems, as pathogens can be transmitted from animals to humans through direct contact, consumption of animal products, or exposure to contaminated environments. The impacts of zoonoses are broad, including increased morbidity and mortality in humans, reduced livestock performance and productivity, economic losses, and social and environmental implications. The complex relationship between humans, animals, and ecosystems demands integrated, comprehensive, and evidence-based control efforts. This review aimed to synthesize recent scientific findings on the impacts of zoonotic diseases along the food production chain, identify risk factors contributing to pathogen spread, and assess various prevention strategies that have been implemented in various contexts. The literature review covers human health, animal welfare, economic, social, and environmental dimensions, with an emphasis on biosecurity, vaccination and animal health interventions, food safety regulations, and the use of technological innovations such as early detection systems and product traceability. The analysis shows that consistent implementation of biosecurity, appropriate veterinary medical interventions, hygienic food processing practices, and technology-based monitoring systems can significantly reduce the risk of zoonotic transmission. A cross-sectoral approach that adopts the One Health principle has been proven to enhance synergy between human health, animal health, and the environment, making risk mitigation efforts more effective and sustainable. Going forward, research is recommended to focus on developing adaptive vaccines, innovating disease detection technologies, improving education for livestock farmers and food workers, and evaluating regulatory policies to strengthen production chain security. This comprehensive approach is expected to strengthen zoonotic control systems, reduce health and economic impacts, and support global food security.

Introduction

Zoonotic diseases, defined as infections that can be transmitted from animals to humans, represent one of the most complex and far-reaching global health challenges (Singh and Singh, 2025). Zoonotic pathogens comprise a wide range of infectious agents, including bacteria, viruses, parasites, and fungi, which may cause illnesses ranging from mild infections to life-threatening conditions (Al Sulivany *et al.*, 2024). Transmission of zoonoses occurs through direct contact with animals, consumption of contaminated animal products, or exposure to contaminated environmental media, indicating that transmission pathways often involve multidimensional interactions among humans, animals, and ecosystems (Esposito *et al.*, 2023). This phenomenon underscores the necessity of an integrative approach to risk management, particularly within the food production sector, which serves as a critical point for pathogen transmission (Singh *et al.*, 2024).

Within the context of the food production chain, zoonotic diseases pose significant challenges because they affect multiple stages, ranging from farming, transportation, processing, and distribution to final consumption (Mulyati *et al.*, 2025). At the farm level, interactions between animals and humans or wildlife, high animal population density, and inadequate biosecurity practices increase the risk of infection (Kurniawan *et al.*, 2025a). During transportation, animal stress and suboptimal sanitary conditions may facilitate pathogen dissemination (Inbaraj *et al.*, 2022). Furthermore, the processing stage of animal-derived products represents another critical control point, where cross-contamination or inconsistent sanitation procedures may allow pathogens to persist until reaching consumers (Shurson *et al.*, 2022). This complexity indicates that each stage

within the food production chain carries distinct risk factors, highlighting the need for holistic and evidence-based mitigation strategies (Galanakis *et al.*, 2025).

The impact of zoonotic diseases is not limited to human health but also extends to economic losses and animal welfare concerns (Shaheen, 2022). In humans, zoonotic infections can result in significant morbidity and mortality, while at the farm level, these diseases reduce productivity, cause animal mortality, and compromise product quality (Raza *et al.*, 2023). Economic losses are further exacerbated by the costs associated with treatment, mass vaccination, quarantine measures, and product recalls from the market (Kurniawan *et al.*, 2025b). On a broader scale, zoonotic outbreaks may disrupt both domestic and international trade, reduce consumer confidence, and affect food market stability (Purbowati *et al.*, 2025). Additionally, social impacts—including changes in consumption patterns, stigma toward certain communities or regions, and ecological pressures resulting from control interventions—add further complexity to zoonosis management (He *et al.*, 2022).

The significance of zoonotic diseases continues to increase alongside the globalization of food trade, intensification of livestock production, and environmental changes (Endah *et al.*, 2025). Increased human–animal interactions, live animal trade practices, and global mobility expand opportunities for pathogen transmission across regions and countries (Istiana *et al.*, 2025a). These factors position zoonosis control not solely as a responsibility of the health sector but as an issue requiring multisectoral collaboration involving animal health, food safety, environmental management, and public policy. The One Health concept, which emphasizes the integration of human, animal, and ecosystem health, has therefore become a primary approach for mitigating zoonotic risks throughout the

food production chain (Erkyihun and Alemayehu, 2022; Kurniawan et al., 2025c).

This review aimed to summarize current evidence regarding the impact of zoonotic diseases within the food production chain, identify risk factors contributing to disease transmission, and evaluate prevention and control strategies implemented across various contexts. The scope of the review encompasses human health, productivity and economic aspects, animal welfare, as well as social and environmental implications. By providing a comprehensive analysis, this review is expected to offer a scientific basis for the development of effective policies, biosecurity practices, and technological innovations to sustainably minimize zoonotic risks.

Method

This literature review was conducted using a systematic approach to ensure comprehensive coverage and data relevance. The inclusion criteria comprised original research articles, review papers, and case reports addressing zoonotic diseases within the context of the food production chain, published in either English or Indonesian. Articles that were not relevant to the main topic, studies with incomplete data, and popular publications or opinion-based articles were excluded to maintain the quality and consistency of the analysis.

The literature search was performed using reputable international scientific databases, including PubMed, Scopus, and Web of Science. The search strategy employed combinations of keywords such as "zoonosis," "food production chain," "livestock," "foodborne pathogens," "biosecurity," and "prevention strategies." The publication period covered the most recent two decades (2018–2026) to ensure relevance to current practices and technological advancements in food production and zoonosis control.

Information synthesis was conducted using thematic and narrative approaches. Articles that met the inclusion criteria were analyzed to identify risk patterns, health and economic impacts, transmission factors, and prevention strategies implemented across various food production contexts. The thematic approach enabled the grouping of data according to major topics, while narrative synthesis provided a conceptual framework integrating empirical evidence with practical recommendations. These methodological steps ensure that the literature review is comprehensive, systematic, and scientifically rigorous, thereby providing a strong foundation for developing zoonosis mitigation strategies throughout the food production chain.

The impact of zoonotic diseases on the food production chain

Zoonotic diseases pose extensive consequences throughout the food production chain, affecting human health, animal productivity, economic stability, and social and environmental dimensions. These impacts arise through direct infection, reduced quality and quantity of animal-derived products, changes in consumer behavior, and ecological pressures, thereby requiring a comprehensive understanding to enable effective risk management (Banik and Basu, 2025). Figure 1 illustrates the triple impact

of zoonotic diseases, demonstrating how these infections simultaneously influence human health, animal productivity, and broader socio-economic and environmental systems. Table 1 summarizes the major impacts of zoonotic diseases across the food production chain, encompassing human health, animal productivity, and economic outcomes, as well as social and environmental implications.

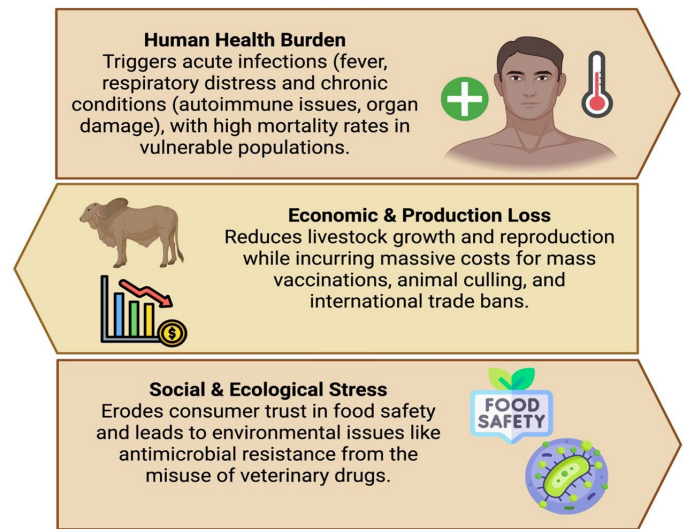


Figure 1. The triple impact of zoonotic diseases.

Human health impacts

Zoonotic diseases impose a complex health burden on humans, ranging from mild infections to life-threatening conditions (Waseem et al., 2023). Zoonotic pathogens may be transmitted through direct contact with animals, consumption of contaminated animal products, or exposure to contaminated environmental media, resulting in a highly variable clinical spectrum (Ali and Alsayeqh, 2022). Acute infections commonly produce systemic symptoms such as fever, malaise, diarrhea, and respiratory disorders, which may progress to severe complications if not promptly managed (Izquierdo-Condoy et al., 2024)

Beyond acute manifestations, zoonotic diseases may also trigger chronic conditions with long-term health consequences (Tazerji et al., 2022). Certain pathogens can induce persistent inflammation, immune dysregulation, or organ damage, thereby increasing the risk of autoimmune disorders or metabolic complications (Blanco and Kaplan, 2023). These chronic conditions further intensify the public health burden, as they require long-term monitoring and continuous medical care, while also elevating the risk of morbidity and mortality among vulnerable populations, including children, the elderly, and immunocompromised individuals (Pisetsky, 2023).

Mortality associated with zoonotic diseases varies depending on the type of pathogen, delays in diagnosis, and the availability of medical facilities (Sharan et al., 2023). Diseases characterized by rapid transmission or resistance to conventional therapies may result in high fatality rates and have the potential to trigger local or global outbreaks (Alara and

Table 1. Impacts of zoonotic diseases along the food production chain.

Impact category	Description	Examples of impact	Source
Human health	Infections resulting from direct contact, consumption of contaminated animal products, or exposure to polluted environments.	Acute infections (fever, diarrhea, respiratory disorders), chronic conditions (persistent inflammation, organ complications), high mortality in vulnerable populations.	(Esposito et al., 2023)
Production and economy	Reduced animal productivity, reproductive disorders, and animal mortality affecting food supply and operational costs.	Financial losses due to treatment, vaccination, quarantine measures, culling, price fluctuations, and export restrictions.	(Raza et al., 2023)
Social and environmental	Changes in consumer behavior, public perception, and ecological consequences resulting from disease control interventions.	Decline in consumer confidence, regional stigma, disruption of local ecosystems, antimicrobial resistance associated with veterinary drug use.	(Tsegaye et al., 2022)

Alara, 2024). Therefore, early detection, timely medical intervention, and evidence-based preventive measures constitute crucial components in reducing the impact on human health (AbdulRaheem, 2023).

The One Health approach, which integrates human, animal, and environmental health, has become increasingly important in mitigating zoonotic risks (Kurniawan et al., 2026). This strategy emphasizes multidisciplinary collaboration, public education, farm biosecurity, and coordinated epidemiological surveillance, thereby enabling effective interventions to reduce infection rates, lower morbidity, and prevent mortality associated with zoonotic diseases (Horefti, 2023).

Impact on production and economy

Zoonotic diseases exert direct pressure on animal productivity, thereby affecting the availability and quality of food products (Hinchliffe et al., 2024). Infections in livestock frequently lead to reduced growth rates, reproductive disorders, and increased mortality, resulting in decreased production output (Capper, 2023). This decline not only affects individual farmers but may also cause supply instability at regional or national levels, particularly for commodities that serve as primary sources of protein (Khatri et al., 2024). In addition to biological losses, zoonotic diseases impose significant economic burdens through treatment costs, mass vaccination programs, and control measures such as quarantine or culling of infected animals (Bose and Kumar, 2025). The withdrawal of animal-derived products from the market due to pathogen contamination further increases financial losses, while disruptions in distribution and logistics may lead to price fluctuations that adversely affect both consumers and industry stakeholders (Bytyqi et al., 2026).

The economic impact of zoonotic diseases is also transboundary in nature. International trade may be disrupted due to export restrictions, stringent food safety certification requirements, or trade bans imposed on affected regions (Istiana et al., 2025b). The accumulation of these losses highlights the importance of evidence-based mitigation strategies, including epidemiological surveillance, farm-level biosecurity, and market protection policies, to minimize financial risks while maintaining the continuity of the food production chain (Subasinghe et al., 2023).

Social and environmental impacts

Zoonotic diseases have significant social implications, particularly through changes in consumer behavior and public perceptions of food safety (Tsegaye et al., 2022). Outbreaks or reported zoonotic cases may reduce public confidence in certain animal-derived products, trigger declines in demand, and lead to market instability (Rani et al., 2026). These events directly affect the livelihoods of farmers and workers within the food sector and may also generate stigma toward specific regions or communities perceived as sources of disease (Majiwa et al., 2024).

Furthermore, the environmental impacts of zoonotic diseases cannot be overlooked. Disease control measures, such as animal quarantine,

culling of infected livestock, and the use of veterinary pharmaceuticals, may generate ecological pressure and environmental residues (Khalifa et al., 2024). Mass culling practices, for instance, can disrupt local ecosystem balance and reduce biodiversity (Sharma and Birman, 2024). The use of antibiotics and pesticides to prevent pathogen spread also increases the risk of antimicrobial resistance, which carries long-term implications for both human and environmental health (Istiana et al., 2025a).

These social and environmental impacts highlight the need for an interdisciplinary approach to zoonotic disease management. Effective strategies integrate One Health principles, strengthen risk communication to the public, and ensure environmentally responsible biosecurity and waste management practices (Kurniawan et al., 2025c). Such approaches not only protect human and animal health but also support ecosystem sustainability and maintain public trust in food products (Nwokedi et al., 2025).

Risk factors for the spread of zoonoses

The transmission of zoonotic diseases within the food production chain is influenced by several risk factors, including production chain conditions, inadequate biosecurity practices, intensive human–animal interactions, and the movement and trade of live animals (Bartlett et al., 2022). Figure 2 illustrates critical risk hotspots along the food chain, demonstrating how zoonotic disease spread is driven by multiple interconnected factors, such as production system characteristics, insufficient biosecurity implementation, and high levels of human–animal contact as well as live animal trade. Table 2 summarizes the key factors contributing to the dissemination of zoonotic diseases within the food production chain.

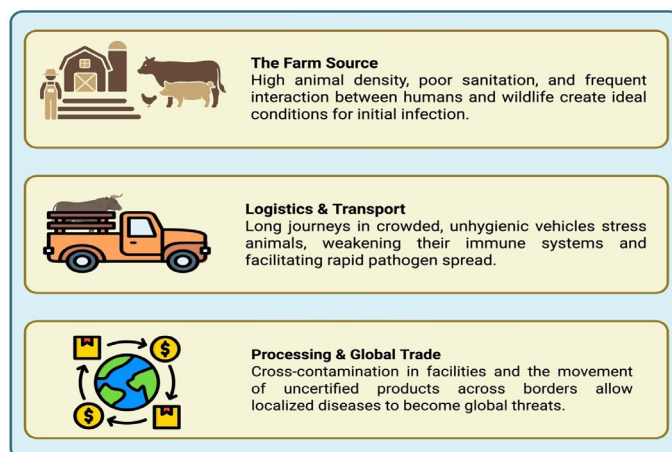


Figure 2. Critical risk hotspots in the food chain.

Production chain

The food production chain represents a critical pathway for zoonotic disease transmission, beginning at the farm level as the primary source

Table 2. Risk factors for zoonotic disease transmission along the food production chain.

Risk factor	Description	Example situations / Impacts	Source
Production chain	Farming, transportation, and processing stages serve as critical pathways for pathogen transmission.	High animal density, limited sanitation, cross-contamination, improper storage temperatures, overcrowded and unhygienic animal transport.	(Sahoo et al., 2022)
Poor biosecurity practices	Inadequate sanitation, isolation of sick animals, access control, and internal monitoring.	Sick animals not isolated, equipment not sterilized, untrained workers, and hygiene protocols neglected.	(Nyokabi et al., 2024)
Human–animal interaction	Intensive direct contact between humans and domestic animals or wildlife.	Feeding activities, cage cleaning, and animal slaughter without hygienic procedures.	(Bartlett et al., 2022)
Live animal markets	Trade of animals under crowded and unhygienic conditions facilitating cross-species contact.	Animals from multiple sources gathered and traded without adequate animal health supervision.	(Rani et al., 2026)
Global trade	Cross-border movement of animals, animal products, and biological materials increases transmission risks.	Export/import of animals or animal products without health certification or traceability systems, triggering transboundary outbreak risks.	(Banik and Basu, 2025)

of pathogens (Elbehiry and Marzouk, 2025). Intensive animal husbandry practices, limited housing sanitation, and interactions between animals, humans, and wildlife increase the likelihood of infection and interspecies transmission (Karmacharya *et al.*, 2024). Emphasizing biosecurity at the farm level, including the isolation of sick animals, sanitation of equipment, and controlled access for personnel and animals, constitutes an effective first preventive strategy to reduce the risk of disease spread (Kurniawan *et al.*, 2025b).

Animal and food product transportation represents the next critical control point. Poor hygienic transport conditions, long travel durations, and overcrowding can elevate animal stress, weaken immune responses, and facilitate pathogen dissemination along distribution routes (Yadav *et al.*, 2024). The use of dedicated transport vehicles, implementation of sanitation protocols before and after transportation, and regulation of optimal stocking density have been shown to reduce the potential for disease transmission during distribution routes (Kurniawan *et al.*, 2026).

The processing stage also constitutes a high-risk phase within the food production chain. Cross-contamination in processing facilities, improper temperature storage, and inconsistent hygiene practices enable pathogens to persist and spread to final products (Mahunu *et al.*, 2024). The implementation of standardized sanitation procedures, separation of processing areas, temperature control, and routine inspections is an essential measure to ensure food safety (Kurniawan *et al.*, 2026). The integration of these measures from farm to processing highlights the importance of the Farm-to-Fork approach, in which each stage of the production chain is systematically managed to minimize zoonotic risks (Ncube, 2025).

Low biosecurity practices

Low levels of biosecurity in farms and animal processing facilities represent a major risk factor for the spread of zoonotic diseases (Nyokabi *et al.*, 2024). Inadequate practices such as sporadic housing and sanitation, unrestricted access of personnel or vehicles to animal areas, and the use of non-sterilized equipment facilitate pathogen persistence and transmission among animals and from animals to humans (Hayek, 2022). These conditions increase the likelihood of direct and indirect contact with sources of infection, thereby elevating disease prevalence within animal populations and increasing the risk of transmission to consumers (Kovács *et al.*, 2025).

Insufficient training and awareness among farmers and workers regarding biosecurity principles also contribute to poor compliance with disease control protocols (Amalraj *et al.*, 2024). For example, failure to isolate sick animals, contamination of feed or water sources, and inconsistent adherence to worker hygiene procedures represent critical points in the zoonotic transmission chain (Rahim, 2025). Furthermore, limited internal monitoring and evaluation often prevent early detection of biosecurity weaknesses until outbreaks occur, resulting in delayed interventions and greater health and economic impacts (Hao *et al.*, 2022).

Consistent implementation of biosecurity measures, including access control, routine sanitation, isolation of diseased animals, and worker education, has been shown to significantly reduce the risk of zoonotic transmission (Jimenez *et al.*, 2023). This approach should be integrated with other preventive strategies, such as vaccination programs, epidemiological surveillance, and early detection technologies, to establish a comprehensive and sustainable risk management system throughout the food production chain (Subasinghe *et al.*, 2023).

Human-animal interactions, live animal markets, and global trade

Intensive interactions between humans and animals, including both domestic animals and wildlife, represent a primary pathway for zoonotic disease transmission (Esposito *et al.*, 2023). Direct contact during animal husbandry, slaughtering, or handling enables pathogens to cross species barriers, particularly when sanitation and biosecurity procedures are inadequate (Rodarte *et al.*, 2023). Routine farm activities such as feeding, cleaning animal housing, or handling sick animals can serve as critical transmission points, highlighting the importance of worker education and training as key components of risk mitigation (Kurniawan *et al.*, 2025a).

Live animal markets also play a significant role in the spread of zoonotic diseases (Endah *et al.*, 2025). Animals originating from multiple sources are often gathered and traded under crowded and unhygienic conditions, facilitating cross-species contact and accelerating pathogen transmission (Olowu *et al.*, 2026). These markets pose risks not only to traders and local consumers but may also serve as amplification points for larger outbreaks in the absence of adequate animal health surveillance and control systems (Istiana *et al.*, 2025a).

Furthermore, global trade expands zoonotic risks to an international scale (Ortiz-Millán, 2025). The movement of animals, animal products, and biological materials across borders allows pathogens that were previously localized to spread into new regions (Hoffman *et al.*, 2023). The globalization of food trade necessitates international standards for animal and food safety, including health certification, quarantine inspections, and transparent traceability systems (Tibebu *et al.*, 2024). Without stringent regulations, the potential for disease transmission increases, leading to public health consequences, economic losses, and disruptions in global food distribution (Rahimi *et al.*, 2022).

The integration of risk management at local, national, and international levels is therefore essential to reduce the impact of zoonotic diseases. Effective strategies include strengthened animal health surveillance, implementation of biosecurity measures in live animal markets, worker training, and compliance with global trade protocols, ensuring that the food production chain remains safe and sustainable (Istiana *et al.*, 2025b; Kurniawan *et al.*, 2025b).

Prevention and control strategies

Prevention and control strategies for zoonotic diseases emphasize

Table 3. Strategies for the prevention and control of zoonotic diseases along the food production chain

Strategy	Description	Example implementation / Impact	Source
Farm-to-Fork approach	Integration of risk control measures throughout the entire production chain, from farms to end consumers.	Farm biosecurity (access control, sanitation, isolation of sick animals), hygienic processing procedures, safe transportation and storage, and product traceability systems.	(Elbehiry and Marzouk, 2025)
Vaccination and medical interventions	Reduction of pathogen prevalence in animal populations and proactive disease control.	Vaccination against <i>Brucella</i> spp., <i>Salmonella</i> spp., and <i>Pasteurella</i> spp.; quarantine of new or sick animals; timely treatment; routine health monitoring.	(Saleem <i>et al.</i> , 2023a)
Policies and regulations	Food safety standards and animal health surveillance to ensure hygienic production and distribution practices.	Routine inspection of farms and processing facilities, certification of healthy animals and food products, mandatory disease reporting programs, international trade regulations.	(Erkyihun and Alemayehu, 2022)
Technology and innovation	Utilization of technology for early detection, monitoring, and traceability across the production chain.	Real-time PCR, ELISA, genomic sequencing, biosensors, IoT-based farm monitoring systems, and food product traceability for contamination source identification.	(Singh <i>et al.</i> , 2024)

an integrated approach that combines biosecurity practices, veterinary medical interventions, food safety regulations, and technological applications to minimize the risk of pathogen transmission throughout the food production chain (Saleem *et al.*, 2023a). Figure 3 illustrates the One Health prevention toolkit, highlighting a comprehensive framework that integrates biosecurity measures, veterinary interventions, food safety governance, and technological innovations to reduce pathogen spread across the food production continuum. Table 3 summarizes the key strategies for zoonosis prevention and control throughout the food production chain.

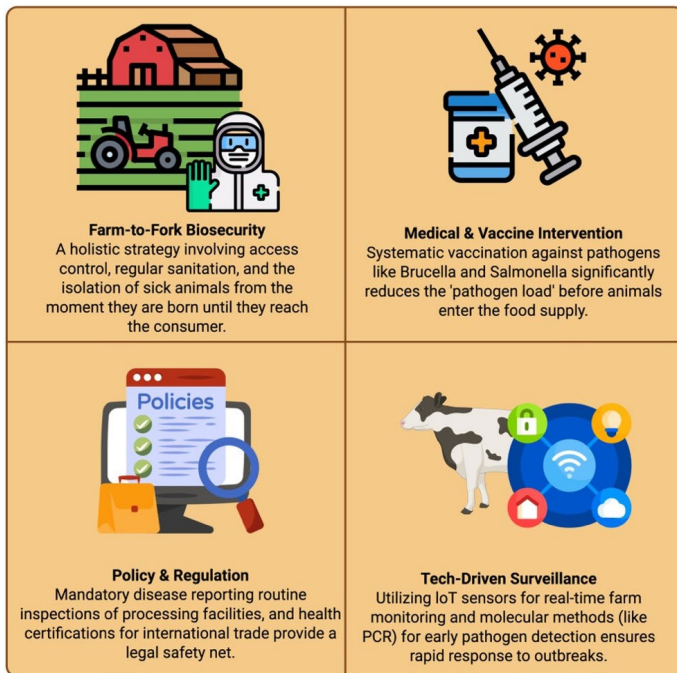


Figure 3. The one health prevention toolkit

Farm-to-fork approach

The Farm-to-Fork approach emphasizes the integration of zoonotic risk control measures throughout the entire food production chain, from primary production at the farm level to the final consumer (Santos *et al.*, 2023). At the farm level, the implementation of strict biosecurity measures serves as the fundamental cornerstone (Mehmedi *et al.*, 2025). These include controlled access for animals and humans, routine sanitation of housing facilities, hygienic feed and water management, and the isolation of diseased animals to prevent pathogen transmission (Kurniawan *et al.*, 2025c). Such strategies help minimize contact with potential sources of infection and reduce disease prevalence within animal populations (Zanon *et al.*, 2024).

At the processing stage, facility hygiene and sanitation play a critical role in preventing cross-contamination (Possas and Perez-Rodríguez, 2023). The processing of animal-derived products must follow standardized hygiene procedures, including proper equipment cleaning, temperature control, and the consistent application of sanitation protocols (Pathak *et al.*, 2024). The adoption of these hygienic practices reduces the likelihood of pathogen survival or proliferation in food products, thereby ensuring food safety for consumers (Chandimali *et al.*, 2025).

Food distribution represents another critical control point within the Farm-to-Fork framework. Safe transportation, appropriate temperature-controlled storage, and packaging designed to prevent external contamination are essential to maintaining product integrity (Kurniawan *et al.*, 2026). In addition, traceability systems that enable tracking of product origin allow rapid response in the event of contamination, facilitating timely interventions before pathogens can spread more widely (Olufemi *et al.*, 2024).

By integrating these three stages, farming, processing, and distribu-

tion, the Farm-to-Fork approach provides a comprehensive framework for reducing zoonotic risks, ensuring food safety, and simultaneously protecting both human and animal health (Kiran *et al.*, 2023). This approach also supports the implementation of One Health principles by promoting collaboration among farmers, food processors, regulators, and consumers (Hassan-Kadle *et al.*, 2025).

Vaccination and medical interventions in animals

Vaccination represents one of the primary strategies for zoonosis prevention, focusing on reducing pathogen prevalence within animal populations before transmission to humans occurs (Salomova *et al.*, 2025). The appropriate and systematic implementation of vaccines can decrease infection burden, reduce pathogen shedding, and limit transmission at the farm level (Endale *et al.*, 2022). A clear example is vaccination against *Brucella* spp. in cattle and goats, which has been shown to reduce the incidence of brucellosis in animals while simultaneously lowering the risk of human infection through the consumption of animal products or direct contact (Douglas *et al.*, 2022).

In addition to brucellosis, vaccination against pathogens such as *Salmonella* spp. and *Pasteurella* spp. has been implemented in various livestock production systems to reduce contamination of meat and processed products (Zenu and Bekele, 2024). These vaccines enhance the animal's immune response to natural infection, thereby limiting bacterial colonization in the gastrointestinal tract or reproductive organs (Correa *et al.*, 2022). The direct impact of these interventions is reflected in improved food product quality and a reduction in outbreaks that may lead to significant economic losses and public health risks (Grace, 2023).

Veterinary medical interventions are not limited to vaccination alone. Timely treatment of infected animals, quarantine of newly introduced or diseased animals, and routine health monitoring constitute integral components of zoonosis control strategies (Marzouk and Alajaji, 2025). This proactive approach enables early disease detection, suppresses pathogen spread, and minimizes zoonotic risks before they reach consumers (Mukherjee *et al.*, 2023). The integration of vaccination and veterinary medical interventions with biosecurity practices and animal health management ensures comprehensive protection, aligning with One Health principles to safeguard both animal and human health while maintaining the safety of the food production chain (Kurniawan *et al.*, 2025c).

Policies and regulations

Policies and regulations play a central role in mitigating zoonotic risks throughout the food production chain (Saleem *et al.*, 2023b). Consistently implemented food safety standards provide a legal framework to ensure hygienic practices in production, processing, and distribution (Overbosch and Blanchard, 2023). These standards encompass requirements for facility sanitation, the proper handling of animal-derived products, and the monitoring of drug residues and biological contaminants, thereby minimizing the risk of contamination and pathogen transmission (Kurniawan *et al.*, 2026).

Animal disease surveillance conducted by relevant authorities also represents a key component of zoonosis control (Engdawork and Negusie, 2025). Surveillance programs include mandatory reporting of specific diseases, routine inspections of farms and processing facilities, and monitoring of pathogen prevalence within animal populations (Sharan *et al.*, 2023). The data collected enable early outbreak detection, informed intervention planning, and evaluation of control strategy effectiveness, allowing preventive measures to be implemented before diseases spread widely (Meckawy *et al.*, 2022).

Food safety certification and animal health certification provide an additional layer of protection, particularly in the context of domestic and international trade (Wirth, 2023). Certified products indicate that the entire production process complies with established safety and quality

standards, enhancing consumer confidence and facilitating market access (Wang *et al.*, 2023). These regulatory measures not only reduce zoonotic risks but also promote sustainable, transparent, and accountable production practices (Erkyihun and Alemayehu, 2022).

Technology and innovation

Technological advancements have created significant opportunities for the prevention and control of zoonotic diseases throughout the food production chain (Sahoo *et al.*, 2022). Early pathogen detection using molecular methods and biosensors enables the identification of infections at an early stage, before widespread transmission occurs (Dikman *et al.*, 2025). These methods, including real-time Polymerase Chain Reaction (PCR), Enzyme-Linked Immunosorbent Assay (ELISA), and genome-based sequencing, improve diagnostic accuracy, accelerate epidemiological response, and enable more targeted interventions (Chisompola *et al.*, 2025).

In addition, digital monitoring systems based on the Internet of Things (IoT) and environmental sensors support real-time surveillance of farm conditions (Patil *et al.*, 2023). Parameters such as temperature, humidity, air quality, and animal vital indicators can be continuously monitored, allowing early detection of changes that may signal disease emergence (Sharma and Shivandu, 2024). The integration of these digital data with analytical algorithms facilitates zoonotic risk prediction and enables faster, evidence-based decision-making (Adegoke *et al.*, 2024).

Traceability, or the ability to track the origin of food products, has also become a key element in food safety innovation (Yu *et al.*, 2022). Through transparent tracking systems, each stage of the production chain from farming and processing to distribution and consumption can be monitored (da Costa *et al.*, 2022). This system allows rapid identification of contamination sources during outbreaks, enabling effective mitigation measures to prevent further spread (Kurniawan *et al.*, 2025a).

Challenges in zoonosis prevention

Zoonotic disease prevention faces multiple challenges, including limited resources at the farm level, the emergence of antimicrobial resistance, the impacts of globalization in the food trade, and low levels of awareness and education among farmers and the general public (Ahmed, 2024; Endah *et al.*, 2025).

Limited resources on the farm

Limited resources at the farm level represent a significant factor influencing the spread of zoonotic diseases (Wang and Hu, 2023). Many small- and medium-scale farms face inadequate sanitation facilities, including insufficient waste management systems, limited access to clean water, and equipment that is rarely sterilized (Kurniawan *et al.*, 2025b). These conditions increase the likelihood of animal exposure to pathogens and facilitate the transmission of infections among animals as well as from animals to humans (Kurniawan *et al.*, 2025c). Limited infrastructure also restricts farmers' ability to consistently implement biosecurity protocols, thereby increasing the risk of disease transmission (Morris *et al.*, 2023).

In addition, the shortage of trained personnel constitutes another major challenge (Kalejaiye, 2023). Farmers and workers who receive limited training in biosecurity practices, feed and water management, and early disease detection are more likely to overlook risk-control procedures (Rahman, 2025). The lack of routine animal health monitoring often results in infections remaining undetected at early stages, leading to delayed intervention and greater health and economic impacts (Nuvey *et al.*, 2022).

Financial constraints further limit farmers' access to vaccines, veterinary medicines, and modern monitoring technologies (Jaime *et al.*, 2022). Consequently, animals become more susceptible to infection, pathogen prevalence increases, and zoonotic risks to consumers also rise (Esposito

et al., 2023). Mitigation strategies should therefore include technical support, capacity building, and adequate resource provision to enable effective implementation of biosecurity and disease control measures (Subasinghe *et al.*, 2023). This approach aligns with the One Health framework, as strengthening farmers' capacity not only protects animal health but also safeguards human health and the integrity of the entire food production chain (Roy *et al.*, 2025).

Antibiotic resistance

Antimicrobial resistance represents one of the greatest challenges in controlling zoonotic diseases within the food production sector (Stevenson, 2023). The uncontrolled use of antibiotics in livestock—both for therapeutic purposes and as growth-promoting feed additives—drives the selection of resistant bacteria (Zheng *et al.*, 2025). These resistant pathogens are not only difficult to manage in animals but can also be transmitted to humans through direct contact, consumption of contaminated meat or animal products, and exposure to environments polluted by livestock waste (Endale *et al.*, 2023).

The presence of resistant bacteria increases the risk of treatment failure in zoonotic infections affecting both humans and animals, prolongs disease duration, and elevates morbidity and mortality rates (Istiana *et al.*, 2025a). The economic impact is also substantial, including increased treatment costs, reliance on more expensive alternative drugs, and potential losses due to reduced animal productivity (Horvat and Kovačević, 2025). Furthermore, antimicrobial resistance diminishes the effectiveness of disease control strategies that traditionally rely on antibiotic therapy as a rapid intervention measure (Endale *et al.*, 2023).

Managing antimicrobial resistance requires a multidimensional approach (Endah *et al.*, 2025). Effective strategies include the prudent use of antibiotics based on appropriate clinical indications, routine surveillance of resistance patterns at the farm level, and farmer education on responsible antimicrobial use practices (Istiana *et al.*, 2025a). In addition, the integration of biosecurity measures, vaccination programs, and proactive veterinary interventions is essential to reduce dependence on antibiotics (Endah *et al.*, 2025). This approach aligns with the One Health framework, as preventing antimicrobial resistance in animals also contributes to protecting human health and ensuring the safety of the food production chain as a whole (Kurniawan *et al.*, 2025c).

Globalization and food trade

Globalization has expanded food distribution networks and animal trade, significantly increasing the potential for zoonotic disease transmission (Purbowati *et al.*, 2025). The cross-border movement of live animals, animal products, and biological materials enables pathogens that were previously geographically confined to spread into new regions (Istiana *et al.*, 2025b). This situation poses not only public health risks but also threatens economic stability and the global food supply (Endah *et al.*, 2025).

International trade requires the implementation of stringent animal and food safety standards (Tibebe *et al.*, 2024). Animal health certification, quarantine inspections, and traceability systems are essential components to ensure that pathogens are not disseminated through trade chains (Royden *et al.*, 2025). Without effective regulation and surveillance, disease spread may trigger transboundary outbreaks, increase control costs, and result in substantial economic losses (Gongal *et al.*, 2022).

Furthermore, food globalization highlights the need for international coordination in zoonotic risk mitigation (Ortiz-Millán, 2025). Such collaboration includes the exchange of epidemiological data, harmonization of biosecurity standards, and the implementation of evidence-based disease control protocols (Aidoo, 2025). Policy integration enables early outbreak detection and rapid response before diseases spread more widely (Isiaka *et al.*, 2024). This approach aligns with the One Health framework,

as preventing zoonotic transmission through global trade simultaneously protects human and animal health while maintaining the sustainability of the entire food production chain (Ahmed, 2024).

Awareness and education of livestock breeders and the community

Awareness and education among farmers and the general public play a crucial role in mitigating zoonotic risks within the food production chain (Nyokabi et al., 2024). Limited knowledge regarding biosecurity principles, clinical signs of disease, and pathogen transmission pathways often leads to poor hygienic animal management practices, thereby increasing the risk of animal infection and transmission to humans (Jimenez et al., 2023). This lack of understanding also contributes to low compliance with sanitation protocols, proper isolation of sick animals, and the appropriate use of medications or vaccines (Endale et al., 2023).

Effective educational programs can enhance awareness and promote behavioral change, enabling the consistent implementation of biosecurity practices (Moya et al., 2025). Practical training for farmers and farm workers, extension programs on hygienic feed and water management, and public outreach regarding zoonotic risks are essential strategies for strengthening local capacity in disease prevention (Ahmed, 2024). Additionally, broader community education on food safety and the safe consumption of animal products can help reduce infection risks and increase public confidence in livestock products (Kwoba et al., 2023).

The application of evidence-based educational approaches allows for more targeted and effective interventions (Santos et al., 2022). For example, training modules tailored to specific livestock commodities, farm conditions, and farmer behavioral patterns are often more effective than generalized campaigns (Mehmedi et al., 2025). Improved awareness and education not only reduce the risk of zoonotic transmission but also support the One Health framework by integrating the protection of human, animal, and environmental health through sustainable behavioral change (Ahmed, 2024).

Conclusion

Zoonotic diseases exert multidimensional impacts throughout the food production chain, affecting human health, animal productivity, economic stability, and social and environmental conditions. Pathogen transmission occurs through complex interactions among humans, animals, and ecosystems, making every stage of the chain from farming and transportation to processing and distribution a critical control point requiring careful risk management.

The most effective prevention strategies include the consistent implementation of farm-level biosecurity, vaccination and veterinary medical interventions, hygienic sanitation and processing practices, and evidence-based surveillance systems. The Farm-to-Fork approach, product traceability, and the application of early detection technologies have also demonstrated significant value in strengthening zoonotic risk mitigation. Integrating the One Health framework promotes multisectoral coordination among human, animal, and environmental health sectors, thereby enabling sustainable reduction of pathogen transmission risks.

Recommendations for future research and policy development include the advancement of vaccines and adaptive detection technologies targeting emerging pathogens, strengthening biosecurity capacity in small-scale farms, reinforcing food safety regulations, and improving education for communities and workers regarding zoonotic risks. These measures are expected to support the development of a comprehensive risk management system, enhance food production chain safety, and reduce the global public health burden.

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Conflict of interest

The authors have declared no conflict of interest.

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