Biosecurity Strategies for Controlling Zoonotic Pathogens in Meat Production and Processing

Muhammad Waqar[1,*], Dian Tria Fatmila[2], Shoib Munir[3] and Ade Trisna[2]

[1]Department of Poultry Production, Faculty of Animal Production and Technology, University of Veterinary and Animal Sciences, Lahore, Pakistan
[2]Department of Animal Science, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Indonesia
[3]Department of Food and Human Nutrition, Government College University, Faisalabad, Pakistan
*Corresponding author: mwaqarvet@gmail.com

Abstract

Many studies indicate that antimicrobial-resistant zoonotic pathogens, in meats, have adverse effects on food safety in production and processing, conducive to human health emergencies. More than two-thirds of new diseases are carried by animals, and that is why it is critical to prevent the spread of such diseases among animals. Controlling spread can also be controlled by enhancing sanitation and practicing quarantine and segregation modes in the food processing plants, monitoring the health of animals passed through the plants, and giving worker hygiene training. Moreover, inadequate design of meat processing plants also determines pathogen control within such establishments. The utilization of modern technologies like the use of blockchain supply chains to monitor the flow of products, robotics, and artificial intelligence in risk evaluation increases product tracing and biosecurity measures. In this chapter, the authors seek to explain basic measures in biosecurity while at the same time reiterating the centrality of technology in reducing the chances of microbial invasion into the food chain. In addition, it covers today's issue on the need to enhance the legislative laws as well as the best ways of implementing the regulations to ensure that the activities of the pathogenic outbreaks are well supervised and controlled across the world to enhance the quality of meat products and safe health for users.

Keyword: Biosecurity strategies, Food safety, Meat production, Robotics monitoring, Zoonotic diseases

Cite this Article as: Waqar M, Fatmila DT, Munir S, and Trisna A, 2025. Biosecurity strategies for controlling zoonotic pathogens in meat production and processing. In: Farooqi SH, Kholik K and Zaman MA (eds), One Health Horizons: Integrating Biodiversity, Biosecurity, and Sustainable Practices. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 189-195. https://doi.org/10.47278/book.HH/2025.124

A Publication of Unique Scientific Publishers

Chapter No: 25-026

Received: 25-Feb-2025
Revised: 15-Apr-2025
Accepted: 18-May-2025

Introduction

Zoonotic diseases, commonly known as zoonoses, are diseases that are naturally transmitted from animals to human beings. Besides food-, water- and vector-borne transmission, direct or indirect contact between people and animals can lead to the transmission of dangerous bacteria, viruses, parasites, and fungi that cause zoonotic diseases. Based on the research, 70% of human diseases are acquired from animals, transmitted by animals and other diseases caused by these animals are highly deadly and can spread as fast as wildfire or pandemics (Carpenter et al., 2022). Other than influencing cattle production and food, zoonotic diseases are responsible for 2.7 million deaths and 2.5 billion diseases in humans every year (Rahman et al., 2020). Especially in the meat processing plant, zoonotic diseases pose a tremendous threat to the safety of food products. Salmonella, *E. coli*, *Avian Influenza* (AI), and *Campylobacter spp*. are among the main culprits (Zhang et al., 2024). Contaminated meat products can cause these diseases from animals to humans and its effects may lead to the development of several diseases, mainly gastrointestinal diseases. To prevent zoonotic diseases from getting into the food chain biosecurity measures are of the essence. The risk of disease transmission can be significantly minimized by implementing the following measures: better hygiene standards, limiting entry into production plants, and enhanced monitoring measures (Subasinghe et al., 2023). Through these measures, the health of the public, livestock, and therefore, the customer is also well protected. The incorporation of biosecurity measures with technology such as automation and robotics for pathogen-free processing, and the use of big data, predictive modeling, and artificial intelligence in biosecurity increase the preparedness for preventing pathogen intrusion in the food system (Sadeghi et al., 2015).

While biosecurity is important in controlling zoonotic pathogens, the literature is surprisingly sparse on its application in meat processing environments. Biosecurity is the management of preventing the entry of pathogens and minimizing the transmission of pathogens (Renault et al., 2022). While biosecurity in animal husbandry has been discussed extensively in the literature, there is very little detailed consideration of biosecurity measures that are intended to prevent zoonotic infection during meat processing.

This chapter aims to explain the pathological challenges in meat production systems, biosecurity in meat processing plants, and enhancement of biosecurity measures through the integration of new technologies such as Artificial Intelligence and automatic systems.

1. Zoonotic Pathogens in Meat Production: Current Challenges

1.1 Overview of Common Zoonotic Pathogens

Meat production pathogens are organisms that are dangerous to human beings. The decrease in pathogenic microorganisms in meat is controlled by the Pathogen Reduction and Hazard Analysis, and Critical Control Point (PR-HACCP) program of the Food Safety and Inspection Service (FSIS) (Williams et al., 2020). It is easy to be exposed to various points like slaughtering animals, handling raw meat, storage conditions, and meat transportation (EFSA, 2022; Rossler et al., 2020). Some bacteria that are commonly detected in meat production are *Salmonella*, *E. coli,* and *Campylobacter* all of which are associated with foodborne illnesses according to Zhou et al. (2020). In meat production, pathogens like Salmonella and E. coli are potential risks to food products of poultry, pork, meat, milk, and eggs (Abebe et al., 2020). Salmonella and *E.coli* may be classified as pathogenic bacteria that may cause gastroenteritis (William et al., 2020; Zhou et al., 2020). The thermotolerant *Campylobacter*, particularly *C. jejuni* is the leading cause of campylobacteriosis infection and broilers are a source of *C. jejuni* in undercooked broiler meat (Rossler et al., 2020).

1.2 Emergence of Antimicrobial-Resistant Zoonotic Pathogens

One of the challenges to global health comes from the increase in antimicrobial resistance (AMR) among pathogens, largely due to the inappropriate and uncontrolled use of antibiotics (Çınar et al., 2024). AMR arises through gene mutations and resistance gene transfer (Almansour et al., 2023). Various pathogens have developed resistance mechanisms, enabling them to withstand antibiotic treatment. For example, *Campylobacter* has shown resistance to several drugs, including fluoroquinolones, macrolides, and amoxicillin-clavulanic acid (Dai et al., 2020). Intensive farming can potentially reduce pathogen entry through biosecurity measures, but it also increases the risk of amplification, spread, and mutation once pathogens enter livestock facilities (Espinosa et al., 2020). Pathogens can be exposed to non-resistant ones through conjugation, transduction, or transformation. Conjugation occurs when pathogens directly contact each other, allowing the recipient cell to acquire the resistance gene. Transduction occurs when resistance genes are transferred via phage and inserted into the recipient cell's chromosome. Transformation occurs when the resistance gene is inserted into the recipient cell's chromosome or plasmid through lysis. The exposed DNA is released by one pathogen and absorbed by another (Jian et al., 2021).

2. Biosecurity Protocols for Controlling Zoonotic Pathogens

2.1 Minimal Water Usage

In slaughterhouses, most water consumption is used for strict sanitation due to the large amount of blood, and solid and semi-solid materials (Bailone et al., 2020). For 100,000 poultry processed in slaughterhouses, 80% of the water consumed can be saved by replacing electronarcosis stunning with a controlled atmosphere, replacing boiling water with hot steam, replacing pre-cooling using water immersion with pre-cooling using air conditioning, reducing the water renewal in the cooling tanks, where this reduction can allow savings from 365,815 to 59,84m^3/day (Bailone et al., 2016). Water is used to clean pathogen-contaminated surfaces, but improper management can spread them. Ozonated water is recommended for its antimicrobial benefits in food processing facilities, potentially preventing *Salmonella* and *E. coli* spread in meat (Kalchayanand et al., 2019; Megahed et al., 2020).

2.2 Waste Management

Slaughterhouse wastewater (SWW) as a by-product in meat production requires proper handling to prevent it from becoming a public health issue for animals and humans (Bailone et al., 2020). Ng et al. (2022) highlighted that SWW treatment methods, including biological, physical, and chemical processes or advance oxidation processes (AOP), can be used independently or in combination, with combination methods being more effective. Thermo-chemical and biological processes are also important in poultry slaughterhouses for organic waste management of their recycling capacity and short processing time, as described by Al-gheethi et al. (2023). Automatic time-closing faucets, pressurized hoses for floor cleaning, mechanical cleaning of solid materials, and precool zones can be used to reduce the volume of wastewater in poultry slaughterhouses (Bailone et al., 2020).

2.3 Quarantine and Segregation Measures

2.3.1 Livestock Quarantine and Segregation

Properly implemented livestock quarantine is a crucial tool to prevent the spread of disease in livestock (Msimang et al., 2022). Quarantine is an important tool to contain diseases that have the potential to flare as outbreaks, including avian influenza (Duan et al., 2023), brucellosis (Sun et al., 2020), foot and mouth disease (Susila et al., 2023) and AMR pathogens (Almansour et al., 2023). Most importantly of all, it is crucial that isolating infected livestock from other livestock is a major preventive measure against disease outbreaks as sick animals can spread the diseases and protect the health of other livestock (Msimang et al., 2022). It also minimizes getting pathogens out of the herd through environmental contamination, including water, air, and shared equipment (such as feed bins) (Endale et al., 2023).

2.3.2 Wildlife Control

Wildlife control is a major factor that can contribute to controlling zoonotic pathogens. (Espinosa et al., 2020). Reduction of contact with wildlife is another way of managing contamination hence employing barriers that can act as security to the livestock (Msimang et al., 2022). Some of the Global Practice principles of extensive rearing of livestock involve minimizing contact with wild animals (Espinosa et al., 2020). Population density and the development of fragmented habitats increase the encroachment of human, livestock, and wildlife interactions, thereby escalating the likelihood of spill-over of zoonoses including AI, WNV, and HIV (Layton et al., 2017).

2.4 Animal Health Monitoring and Surveillance

2.4.1 Routine Animal Health Checks

Regular health checks are crucial to ensuring animals are free from zoonotic infections (Rahman et al., 2020). Brucellosis, a significant zoonosis, affects animals and humans in various clinical forms, including reproductive symptoms and systemic issues, yet awareness of routine health checks remains low, particularly in developing nations. For example, Tebug et al. (2014) reported that there were no periodic examinations in the northern region of Malawi, despite the presence of Brucella antibodies in dairy cows, indicating brucellosis infections in the region.

2.4.2 Real-Time Disease Surveillance Technologies

In the recent past, most farms have been employing cameras with the Internet of Things (IoT) to keep track of the surrounding environment. The use of sensors in meat production is often referred to as Precision Livestock Farming (PLF), which involves modern information technology in controlling the production process. Biometric sensors can help mitigate disease spread by monitoring temperature, behavior, sound, and physiological parameters including pH, metabolic activity, pathogens, and the presence of toxins and antibiotics in the body (Neethirajan & Kemp, 2021). In addition, blockchain technology enhances transparency, and is also another effective technology for rebuilding consumer trust after animal disease outbreaks (Arvana et al., 2023).

2.4.3 Vaccination Programs

Vaccination provides an important layer of biosecurity for the management of livestock diseases (Layton et al., 2017). Msimang et al. (2022) reported that vaccination is the second most frequently reported biosecurity measure, where in his study among respondents 35% of private farmers had vaccinated their livestock against Brucellosis. Humans also benefit from vaccination against zoonotic diseases (Dai et al., 2020). Moreover, plant-based vaccines have been introduced to reduce antibiotic use in livestock and avoid the development of strains that are resistant to antibiotics, especially epidemic pathogens and zoonoses (Shahid & Daniel, 2016).

3. Role of Biosecurity in Meat Processing Plants

3.1 Meat Processing Facility Design

3.1.1 Zoning and Airflow Management in Processing Plants

The division of facilities into clean and dirty zones helps to prevent cross-contamination and microbial risks, as well as improve food safety (Oliveira et al., 2020). Pathogen contamination in meat production can occur throughout the entire production chain, from farms to transportation to slaughterhouses. To reduce the spread of external pathogen contamination, the establishment of Critical Control Point (CCP) and Good Manufacturing Practices (GMP) in Hazard Analysis and Critical Control Point (HACCP) systems is necessary (Mustefa, 2021). Plants must have adequate natural or mechanical ventilation to provide fresh air for food workers (± 8 liters per person per minute) without contaminating the product (Holah, 2014). Localized airflow management, such as using HEPA filters, can reduce contamination risks during raw product handling (Holah, 2023). Sensors are essential for air quality monitoring to ensure the proper functioning of the ventilation system. (Camarillo-Escobedo et al., 2022).

3.2 Worker Hygiene and Biosecurity Training

Pathogens can infiltrate products through workers' hands, necessitating the implementation of comprehensive hygienic measures to prevent contamination (Margas & Holah, 2014). Contamination sources must be controlled beyond workers' hands, including footwear, and clothing as they directly contact the external environment and raw material. Antimicrobial textiles are increasingly used in factory uniforms to prevent pathogenic contamination, while multi-sanitizers and rotational use are crucial for controlling contamination from pedestrian traffic (Hendricks et al., 2018). Non-conformity with food safety requirements often occurs due to a lack of food safety knowledge, lack of food safety/HACCP control and meat non-conformities control increasing the risk of food safety loss (Jakubowska-Gawlik et al. 2022). Quality training can enhance knowledge about zoonotic disease risks and influence decision-making, such as increasing awareness of PPE use (Nyokabi et al., 2024). Recognizing zoonotic diseases is essential in increasing workers' awareness of biosecurity implemented in factories, especially their transmission and control (Nyokabi et al. 2024). According to Martha et al. (2019), the study evaluated worker behavior before and after training on zoonotic disease prevention, revealing an increase in awareness and effectiveness.

3.3 Pathogen Monitoring in Processing Plants

Many approaches can be used to identify pathogens, however nucleic acid-based methods such as Real-Time PCR and vPCR combined with sequencing approaches are more widely used than immunoassay and NGS-based approaches to detect pathogens (Aladhadh, 2023). In the past few years, fluorescent-based assays have been widely used to detect several pathogens quickly and efficiently, one of which is fluorescent biosensors that utilize nanotechnology for the detection of *E. coli* and *Salmonella* (Pebdeni et al., 2022; Shen et al., 2020). Nanomaterials, with their high sensitivity and selectivity, have advantages over conventional organic dyes in fluorescent-based pathogen detection methods (Kakkar et al., 2023). Nowadays, meta-omics technology approaches have been developed to prevent the spread of pathogens, for the meat food category the sequencing approach can be in the form of metabarcoding (16S rRNA) (Billington et al., 2022). Zwirzitz et al. (2020) reported the use of high-throughput full-length 16S rRNA gene sequencing to identify bacterial community structures in pork processing in factories and stated that high-throughput full-length 16S rRNA genes have great potential in food monitoring applications. The whole genome sequencing (WGS) or metagenomic shotgun sequencing has been proposed to achieve strain-level resolution and is thought to be necessary to track microbes during food processing, but one of the considerations in the application of WGS, especially in developing countries is the cost (Billington et al. 2022).

4. Integrating Technology into Biosecurity Practices

4.1 Blockchain for Meat Traceability

4.1.1 Blockchain-Based Supply Chain Monitoring

Blockchain technology improves transparency and accountability in the meat industry by offering a decentralized, enduring ledger for supply chain monitoring. It has 3 types including centralized, decentralized, and distributed systems. In the distributed system, every person responsible has full access to the data as it is in the chain (Subramanian et al., 2020). Blockchain-based quality control in meat production ensures safety and authenticity by tracking transactions from farm to fork, preventing zoonotic disease entry, and adhering to biosecurity regulations. Unique product identities simplify monitoring, while real-time IoT devices reduce contamination risks (van Hilten et al., 2020). Neogen facilitates tracking an animal's genetic profile, including its diet and medical history (Einstein-Curtis, 2020). A blockchain-based traceability system16 is already in place in Zimbabwe (Global, 2021).

4.2 Automation and Robotics in Meat Processing

4.2.1 Use of Robotics for Pathogen-Free Processing

Robotics are transforming the livestock processing industry by minimizing human interaction and reducing the likelihood of the transmission of zoonotic pathogens (Saravanan, 2023). SCOTT Technology's sophisticated systems automate lamb boning, thereby reducing waste and guaranteeing high precision (de Medeiros Esper et al., 2024). The GRIBBOT robot from SINTEF employs 3D vision technology to extricate chicken fillets with precision. These automation technologies enhance the meat industry's overall efficacy by improving productivity, biosecurity measures, and ensuring the safety and sustainability of food production (Misimi et al., 2018).

4.3 Predictive Analytics and Artificial Intelligence (AI) in Biosecurity

4.3.1 AI-Driven Risk Assessment

AI, specifically predictive analytics, is finding its way into biosecurity in the processing and production of meat. Better still, implementing machine learning algorithms, and long-term memory models can predict times of disease outbreak predictions (Zhao et al., 2024). This way minimizes the risk of zoonotic spread and protects the population's health through better early identification and targeting interventions. Sadeghi et al. (2015) applied a neural network to identify *C. perfringens*, while Yoon et al. (2020) applied deep learning models to assess *Avian (A.) influenza* and Yoo et al. (2022) employed Bayesian logistic regression and extreme gradient boosting models to predict the probability of *A. influenza* virus in chicken.

5. Regulatory Framework and Industry Standards

5.1 International Biosecurity Standards

The World Organization for Animal Health (OIE) disease notification system is made of an epidemiological alert system of the main events and a general notification system of animal health indicators (Jebara et al., 2012). Several international organizations such as FAO, OIE, and WHO use the One Health approach in the detection and prevention of zoonotic diseases (Rai et al., 2024). FAO (2022) defines biosecurity as a strategic, multi-disciplinary discipline of managing risks to human, animal, plant, and environmental health based on the One Health approach; In this case, FAO developed the progressive management pathway for terrestrial animal biosecurity (PMP-TAB) by Militzer et al. 2023. Further, the FAO RLC deployed the FAO situation analysis tool fostered on the One Health approach for the containment of AMR (Caipo et al., 2023).

5.2 National Biosecurity Regulations

Australia, being a big exporter of meat, has adopted tough measures of biosecurity, including the Biosecurity Act of 2015 to avoid the spread of diseases crossing from animals to human beings (Durant & Fuance, 2018). The EU, being one of the largest exporters, has several regulations that offer the highest standards of food safety internationally including 178/2002/EC, 882/2004/EC, 853/2004/EC, and 854/2004/EC (Rossi et al. 2020; Pettoello-Mantovani & Olivieri 2022). Besides, the United States has several measures concerning the biosecurity of meat export as follows, the Federal Meat Inspection Act (FMIA)/1906, the Agricultural Marketing Act/1946, the Export Control Act/1949, and the Food Safety Modernization Act (FSMA)/2011 (Ufer et al., 2023).

5.3 Auditing and Certification Programs

Third-party audits are crucial as they offer suggestions for enhancing insufficient procedures and enhancing accountability to current biosecurity standards(Gillum et al., 2024). The United Kingdom Accreditation Service defines certification as a third-party audit to assess an organization's compliance with certain standards, which through certification can demonstrate compliance with biosecurity standards that can change practices in the supply chain (Marzano et al., 2021).

7. Challenges and Future Directions

The implementation of biosecurity in meat production in Low- and middle-income countries (LMICs) is a challenge due to inadequate funds, inadequate knowledge, and training, and weak rules and policies. To overcome the challenges of future research, it must develop sound biosecurity policies as well as biological tracking systems, innovative methods for biological tracking, and environmentally friendly industrial systems with built-in biosecurity measures. Therefore, international cooperation is crucial for the development of adequate and stable meat production systems against zoonotic threats and for the creation of suitable general frameworks. Some of the policies include the development and enhancement of regulatory systems, surveillance and monitoring, upgraded veterinarian supervision, biosecurity education for employees, and improving international cooperation and standardization with the flow of information. Many also require enhanced support for research in new ways of managing and identifying infections. Small-scale manufacturers also need financial incentives and support which would ensure that as many people as possible are adhering to the rules.

Conclusion

Controlling zoonotic pathogens within meat production and processing is best done with strict biosecurity measures in place. Pathogen transfer poses a significant threat that can be now/sources dramatically reduced by exercises such as staff training, quarantine measures, and sanitation regimes. Moreover, including progressive technologies such as blockchain and risk evaluations conducted with the help of AI enhances supply chain management. These biosecurity activities require increased adaptation to an industry standard and corresponding regulatory framework as zoonotic diseases remain a threat to human health. All in all, the protection of consumer health and the provision of safer meat products will be as sure when people apply a complex approach to achieving these aims.

References

Abebe, E., Gugsa, G., & Ahmed, M. (2020). Review on major food-borne zoonotic bacterial pathogens. *Journal of Tropical Medicine*, 4674235, doi: 10.1155/2020/4674235.

Al-Gheethi, A., Ma, N. L., Rupani, P. F., Sultana, N., Yaakob, M. A., Mohamed, R. M. S. R., & Soon, C. F. (2021). Biowastes of slaughterhouses and wet markets: an overview of waste management for disease prevention. *Environmental Science and Pollution Research*, *30*, 71780-71793, doi: 10.1007/s11356-021-16629.

Aladhadh, M. (2023). A review of modern methods for the detection of foodborne pathogens. *Microorganisms*, *11*, 1111, 1-20, doi: 10.3390/microorganisms11051111.

Alhadlaq, M. A., Aljurayyad, O. I., Almansour, A., Al-Akeel, S. I., Alzahrani, K. O., Alsalman, S. A., Yahya, R., Al-hindi, R. R., Hakami, M. A., Alshahrani, S. D., Alhumeed, N. A., Moneea, A. M., Al-Seghayer, M. S., AlHarbi, A. L., Al-Reshoodi, F. M., & Alajel, S. (2024). Overview of pathogenic Escherichia coli, with a focus on Shiga toxin-producing serotypes, global outbreaks (1982–2024) and food safety criteria. *Gut Pathogens*, *16*(57), 1-18, doi: 10.1186/s13099-024-00641-9.

Almansour, A. M., Alhadlaq, M. A., Alzahrani, K. O., Mukhtar, L. E., Alharbi, A. L., & Alajel, S. M. (2023). The silent threat: antimicrobial-resistant pathogens in food-producing animals and their impact on public health. *Microorganisms*, *11*, 2127, 1-25, doi: 10.3390/microorganisms11092127.

Andino, A., & Hanning, I. (2015). Salmonella enterica: survival, colonization, and virulence differences among serovars. *The Scientific World Journal*, 520179, 1-16, doi: 10.1155/2015/520179.

Arvana, M., Rocha, A. D., & Barata, J. (2023). Agri-food value chain traceability using blockchain technology: Portuguese hams' production scenario. *Foods*, *12*, 4246, 1-27, doi: 10.3390/foods12234246.

Bailone, R. L., Roça, R. O., de Aguiar, L., & Harris, M. (2016). Main technical differences in the processing of broilers: a comparison between slaughterhouses in Brazil and UK. *Journal of Agricultural Science and Technology A*, *6*(2), 136-142, doi: 10.17265/2161-6256/2016.02.007.

Bailone, R., Roça, R., Fukushima, H., & de Aguiar, L. K. (2020). Sustainable water management in slaughterhouses by cleaner production methods—a review. *Renewable Agriculture and Food Systems*, 1-10, doi: 10.1017/S1742170520000083.

Billington, C., Kingsbury, J. M., & Rivas, L. (2022). Metagenomics approaches for improving food safety: a review. *Journal of Food Protection*, *85*(3), 448-464, doi: 10.4315/JFP-21-301.

Caipo, M., Gatica, M. Á., Rojas, H., & del Barrio, L. (2023). A qualitative approach for a situation analysis of AMR risks in the food animal production sector. *Frontiers in Veterinary Science*, *10*, 1045276, 1-14, 10.3389/fvets.2023.1045276.

Callan, R. J., & Garry, F. B. (2002). Biosecurity and bovine respiratory disease. *The Veterinary Clinics Food Animal Practice*, *18*, 57-77.

Camarillo-Escobedo, R., Flores, J. L., Marin-Montoya, P., García-Torales, G., & Camarillo-Escobedo, J. M. (2022). Smart multi-sensor system for remote air quality monitoring using unmanned aerial vehicle and LoRaWAN. *Sensors*, *22*, 1706, 1-29, doi: 10.3390/s22051706.

Carpenter, A., Waltenburg, M. A., Hall, A., Kile, J., Killerby, M., Knust, B., Negron, M., Nicholas, M., Wallace, R. M., Behravesh, C. B., McQuiston, J. H., & the Vaccine Preventable Zoonotic Disease Working Group. (2022). Vaccine preventable zoonotic diseases: Challenges and opportunities for public health progress. *Vaccines*, *10*, 993, 1-19, doi: 10.3390/ vaccines10070993.

Çınar, A. A., Waqas, M., Nastoh, N. A., Waqar, M., & Salman, M. (2024). Supplementation of Various Biotics in Poultry Nutrition for Optimizing Well-Being. *Complementary and Alternative Medicine: Feed Additives*, 291-300, doi: 10.47278/book.CAM/2024.349.

Coburn, B. J., Wagner, B. G., & Blower, S. (2009). Modeling influenza epidemics and pandemics: insights into the future of swine flu (H1N1). *BMC Medicine*, *7*(30), 1-8, doi: 10.1186/1741-7015-7-30.

Dai, L., Sahin, O., Grover, M., & Zhang, Q. (2020). New and alternative strategies for the prevention, control, and treatment of antibiotic-resistant Campylobacter. *Translational Research*, *223*, 76-88, doi: 10.1016/j.trsl.2020.04.009.

de Medeiros Esper, I., Gangsei, L. E., Cordova-Lopez, L. E., Romanov, D., Bjørnstad, P. H., Alvseike, O., From, P. J., & Mason, A. (2024). 3D model based adaptive cutting system for the meat factory cell: overcoming natural variability. *Smart Agricultural Technology*, *7*, 100388.

Durant, S., & Faunce, T. (2018). Analysis of Australia's new biosecurity legislation. *Medical Low Reporter, 25*(3), 647-654.

EFSA Panel on Biological Hazards (BIOHAZ), Koutsoumanis, K., Allende, A., Álvarez-Ordóñez, A., Bolton, D., Bover-Cid, S., Chemaly, M., Davies, R., Cesare, A. D., Herman, L., Hilbert, F., Lindqvist, R., Nauta, M., Ru, G., Simmons, M., Skandamis, P., Suffredini E., Argüello-Rodríguez, H., Dohmen, W., Magistrali, C. F., Padalino, B., Tenhagen, B., Threlfall, J., García-Fierro, R., Guerra, B., Liébana E., Stella, P & Peixe, L. (2022). Transmission of antimicrobial resistance (AMR) during animal transport. *EFSA Journal*, *20*(10), 7586, doi: 10.2903/j.efsa.2022.7586.

Ehuwa, O., Jaiswal, A. K., & Jaiswal, S. (2021). Salmonella, food safety and food handling practices. *Foods*, *10*, 907, 1-16, doi: 10.3390/foods10050907.

Einstein-Curtis, A. (2020). Blockchain brings traceability to animal feed, safety and production. In: Feed Navigator. https://www. feednavigator. com/Article/2020/03/20.

Espinosa, R., Tago, D., & Treich, N. (2020). Infectious diseases and meat production. *Environmental and Resource Economics*, *76*, 1019-1044, doi: 10.1007/s10640-020-00484-3.

Ferry, M., Ranucci, E., Romagnoli, P., & Giaccone, V. (2015). Antimicrobial resistance: A global emerging threat to public health systems. *Critical*

Reviews in Food Science and Nutrition, *57*(13), 2857-2876, doi: 10.1080/10408398.2015.1077192.

Gillum, D. R., Tran, A., Fletcher, J., & Vogel, K. M. (2024). Bridging biosafety and biosecurity gaps: DURC and ePPP policy insights from US institutions. *Frontiers in Bioengineering and Biotechnology*, *12*, 1476527.

Global, E.-L. (2021). E-Livestock Global launch Mastercard blockchain-based solution to bring visibility to the cattle industry in Zimbabwe. *The Dairy Mail*, *28*(8), 21-22.

Hendricks, M. B., Tolen, T. N., Thippareddi, H., Anding, J., Moore, L. L., Griffin, D., & Taylor, T. M. (2018). Sanitary Carcass Dressing and Food Safety Practices in South Central US Small and Very Small Establishments Manufacturing Fresh and Not-Ready-to-Eat Pork Products. *Food Protection Trends*, *38*(1), 52-62.

Holah, J. (2023). Hazard control by segregation in food factories. In *Hygienic Design of Food Factories* (pp. 259-286). Elsevier.

Jakubowska-Gawlik, K., Kolanowski, W., Murali, A. P., & Trafialek, J. (2022). A comparison of food safety conformity between cattle and pig slaughterhouses. *Food Control*, *140*, 109143, 1-8, doi: 10.1016/j.foodcont.2022.109143.

Jian, Z., Zeng, L., Xu, T., Sun, S., Yan, S., Yang, L., Huang, Y., Jia, J., & Dou, T. (2021). Antibiotic resistance genes in bacteria: Occurrence, spread, and control. *Journal of Basic Microbiology*, *61*, 1049-1070, doi: 10.1002/jobm.202100201.

Kakkar, S., Gupta, P., Kumar, N., & Kant, K. (2023). Progress in fluorescence biosensing and food safety towards point-of-detection (pod) system. *Biosensors*, *13*, 249, 1-18, doi: 10.3390/bios13020249.

Kalchayanand, N., Worlie, D., & Wheeler, T. (2019). A novel aqueous ozone treatment as a spray chill intervention against Escherichia coli O157: H7 on surfaces of fresh beef. *Journal of Food Protection*, *82*(11), 1874-1878, doi: 10.4315/0362-028X.JFP-19-093.

Layton, D. S., Choudhary, A., & Bean, A. G. D. (2017). Breaking the chain of zoonoses through biosecurity in livestock. *Vaccine*, *35*, 5967-5973, doi: 10.1016/j.vaccine.2017.07.110.

Margas, E., & Holah, J. T. (2014). Personal hygiene in the food industry. In *Hygiene in Food Processing* (pp. 408-440). Woodhead Publishing.

Martha, E., Sari, N., Dewi, A., & Normala, S. (2019). Education strategies for preventing zoonotic disease transmission among breeders, traders, and slaughterhouse workers. *Journal of International Dental and Medical Research*, *12*(4), 1681-1685.

Marzano, M., Dunn, M., & Green, S. (2021). Perceptions of biosecurity-based accreditation in the plant trade: a UK example. *Forests*, *12*, 1741, 1-19, doi: 10.3390/f12121741.

Megahed, A., Aldridge, B., & Lowe, J. (2020). Antimicrobial efficacy of aqueous ozone and ozone–lactic acid blend on Salmonella-contaminated chicken drumsticks using multiple sequential soaking and spraying approaches. *Frontiers in Microbiology*, *11*, 593911, 1-11, doi: 10.3389/fmicb.2020.593911.

Militzer, N., McLaws, M., Rozstalnyy, A., Li, Y., Dhingra, M., Auplish, A., Mintiens, K., Sabirovic, M., von Dobschuetz, S., & Heilmann, M. (2023). Characterising biosecurity initiatives globally to support the development of a progressive management pathway for terrestrial animals: A Scoping review. *Animals*, *13*, 2672, 1-20, doi: 10.3390/ani13162672.

Misimi, E., Olofsson, A., Eilertsen, A., Øye, E. R., & Mathiassen, J. R. (2018). Robotic handling of compliant food objects by robust learning from demonstration. 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),

Msimang, V., Rostal, M. K., Cordel, C., Machalaba, C., Tempia, S., Bagge, W., Burt, F. J., Karesh, W. B., Paweska, J. T. & Thompson, P. N. (2022). Factors affecting the use of biosecurity measures for the protection of ruminant livestock and farm workers against infectious diseases in central South Africa. *Transboundary and Emerging Diseases*, *69*, 1899-1912, doi: 10.1111/tbed.14525.

Mustefa, W. S. (2021). Review on application of hazard analysis critical control point in ethiopian Slaughtering plant. *International Journal of Veterinary Science and Research*, *7*(1), 040-056.

Neethirajan, S., & Kemp, B. (2021). Digital livestock farming. *Sensing and Bio-Sensing Research*, *32*, 100408, 1-12, doi: 10.1016/j.sbsr.2021.100408.

Ng, M., Dalhatou, S., Wilson, J., Kamdem, B. P., Temitope, M. B., Paumo, H. K., Djelal, H., Assadi, A. A., Nguyen-Tri, P., & Kane, A. (2022). Characterization of slaughterhouse wastewater and development of treatment techniques: A review. *Processes*, *10*, 1300, 1-28, doi: 10.3390/pr10071300.

Njoya, H. F., Awolu, M. M., Christopher, T. B., Duclerc, J. F., Ateudjieu, J., Wirsiy, F. S., Atuhaire, C., & Cumber, S. N. (2021). Prevalence and awareness of mode of transmission of typhoid fever in patients diagnosed with Salmonella typhi and paratyphi infections at the Saint Elisabeth General Hospital Shisong, Bui Division, Cameroon. *Pan African Medical Journal*, *40*(83), 1-9, doi: 10.11604/pamj.2021.40.83.16893.

Nyokabi, N. S., Phelan, L., Lindahl, J. F., Berg, S., Muunda, E., Mihret, A., Wood, J. L. N. & Moore, H. L. (2024). Exploring veterinary students' awareness and perception of zoonoses risks, infection control practices, and biosecurity measures in Ethiopia. *Frontiers in Veterinary Science*, *11*, 1385849, doi: 0.3389/fvets.2024.1385849.

Oliveira, M., Tiwari, B. K., & Duffy, G. (2020). Emerging technologies for aerial decontamination of food storage environments to eliminate microbial cross-contamination. *Foods*, *9*, 1779, 1-16, doi: 10.3390/foods9121779.

Olsen, A., Bonardi, S., Barco, L., Sandberg, M., Langkabel, N., Roasto, M., Majewski, M., Brugger, B., Kautto, A. H., Blagojevic, B., Cota, J. B., Nagel-Alne, G. E., Huneau, A., Laukkanen-Ninios, R., Lebouquin-Leneveu, S., Alvseike, O., Fredriksson-Ahomaa, M., Vieira-Pinto, M., & Kaukonen, E. (2024). A comparison of European surveillance programs for Campylobacter in broilers. *Food Control*, *155*, 110059, 1-9, doi: 10.1016/j.foodcont.2023.110059.

Pebdeni, A. B., Roshani, A., Mirsadoughi, E., Behzadifar, S., & Hosseini, M. (2022). Recent advances in optical biosensors for specific detection of E. coli bacteria in food and water. *Food Control*, *135*, 108822, 1-17, doi: 10.1016/j.foodcont.2022.108822.

Pettoello-Mantovani, C., & Olivieri, B. (2022). Food safety and public health within the frame of the EU legislation. *Global Pediatrics*, *2*, 100020, 1-6, doi: 10.1016/j.gpeds.2022.100020.

Rahman, M. T., Sobur, M. A., Islam, M. S., Ievy, S., Hossain, M. J., El Zowalaty, M. E., Rahman, A. M. M. T., & Ashour, H. M. (2020). Zoonotic disease: Etiology, impact, and control. *Microorganisms*, *8*, 1405, 1-34, doi: microorganisms8091405.

Rai, B. D., Tessema, G. A., Fritschi, L., & Pereira, G. (2024). The application of the One Health approach in the management of five major zoonotic diseases using the World Bank domains: A scoping review. *One Health*, *18*, 100695, 1-15, doi: 10.1016/j.onehlt.2024.100695.

Rao, V., Eilers, A., & Mancini, C. (2006). Select agents diagnostic test reporting requirements—exemptions and implications to biosecurity. *Applied Biosafety*, *11*(4), 215-221.

Renault, V., Humblet, M. F., & Saegerman, C. (2021). Biosecurity concept: Origins, evolution and perspectives. *Animals*, *12*, 63, 1-6, doi: 10.3390/ani12010063.

Rossi, A., Rossi, G., Rosamilia, A., & Micheli, M. R. (2020). Official controls on food safety: Competent Authority measures. *Italian Journal of Food Safety*, *9*, 8607, 125-131, doi: 10.4081/ijfs.2020.8607.

Rossler, E., Olivero, C., Soto, L. P., Frizzo, L. S., Zimmermann, J., Rosmini, M. R., Sequeira, G. J., Signorini, M. L., & Zbrun, M. V. (2020). Prevalence, genotypic diversity and detection of virulence genes in thermotolerant Campylobacter at different stages of the poultry meat supply chain. *International Journal of Food Microbiology*, *326*, 108641, 1-10, doi: j.ijfoodmicro.2020.108641.

Saravanan, S. (2023). Transforming the Medical Landscape: Applications of Robotics and Artificial Intelligence in Combating Infectious Diseases. *Global Biosecurity*, *5*.

Shahid, N., & Daniell, H. (2016). Plant-based oral vaccines against zoonotic and non-zoonotic diseases. *Plant Biotechnology Journal*, *14*, 2079-2099, doi: 10.1111/pbi.12604.

Shen, Y., Huang, Y., Zhang, P., Guo, B., Jiang, H., Tan, C., & Jiang, Y. (2020). Fluorescence sensor array for discrimination of urine proteins and differentiation diagnosis of urinary system diseases. *ACS Applied Bio Materials*, *3*(9), 5639-5643, doi: 10.1021/acsabm.0c00845.

Subasinghe, R., Alday-Sanz, V., Bondad-Reantaso, M. G., Jie, H., Shinn, A. P., & Sorgeloos, P. (2023). Biosecurity: Reducing the burden of disease. *Journal of the World Aquaculture Society*, *54*(2), 397-426, doi: 10.1111/jwas.12966.

Subramanian, N., Chaudhuri, A., & Kayıkcı, Y. (2020). *Blockchain and supply chain logistics:Evolutionary case studies*. Springer Nature.

Sun, G. Q., Li, M. T., Zhang, J., Zhang, W., Pei, X., & Jin, Z. (2020). Transmission dynamics of brucellosis: Mathematical modelling and applications in China. *Computational and Structural Biotechnology Journal*, *18*, 3843-3860, doi: 10.1016/j.csbj.2020.11.014.

Susila, E. B., Daulay, R. S. D., Hidayati, D. N., Prasetyowati, S. R. B., Wriningati, Andesfha, E., Irianingsih, S. H., Dibia, N., Faisal, Supriyadi, A., Yupiana, Y., Hidayat, M. M., Zainudin, N., & Wibawa, H. (2023). Detection and identification of foot-and-mouth disease O/ME-SA/Ind-2001 virus lineage, Indonesia, 2022. *Journal of Applied Animal Research*, *51*(1), 487-494, doi: 10.1080/09712119.2023.2229414 .

Tebug, S. F., Chagunda, M. G., Mapemba, J. P., Awah-Ndukum, J., Tebug, S. F., & Wiedemann, S. (2014). Risk, knowledge and preventive measures of smallholder dairy farmers in northern Malawi with regard to zoonotic brucellosis and bovine tuberculosis. *Onderstepoort Journal of Veterinary Research*, *81*(1), 1-6, doi: 10.4102/ojvr.v81i1.594.

U. S. Department of Agriculture. (2024). *Law and Regulations.* Author.

van Hilten, M., Ongena, G., & Ravesteijn, P. (2020). Blockchain for organic food traceability: Case studies on drivers and challenges. *Frontiers in Blockchain*, *3*, 567175.

Williams, M. S., Ebel, E. D., Saini, G., & Nyirabahizi, E. (2020). Changes in Salmonella contamination in meat and poultry since the introduction of the pathogen reduction and hazard analysis and critical control point rule. *Journal of Food Protection*, *83*(10), 1707-1717, doi: 10.4315/JFP-20-126.

Zhou, Q., Gu, R., Li, P., Lu, Y., Chen, L., & Gu, Q. (2020). Anti-Salmonella mode of action of natural L-phenyl lactic acid purified from Lactobacillus plantarum ZJ316. *Applied Microbiology and Biotechnology*, *104*, 5283-5292, doi: 10.1007/s00253-020-10503-4.

Zwirzitz, B., Wetzels, S. U., Dixon, E. D., Stessl, B., Zaiser, A., Rabanser, I., Thalguter, S., Pinior, B., Roch, F., Strachan, C., Zanghellini, J., Dzieciol, M., Wagner, M., & Selberherr, E. (2020). The sources and transmission routes of microbial populations throughout a meat processing facility. *Biofilms and Microbiomes*, *26*, 1-12, doi: 10.1038/s41522-020-0136-z.