Antimicrobial Resistance in *Escherichia coli* in Livestock; Zoonotic Transmission & Implications for Public Health

Syed Sohail Ahmad[1,*], Maria Nazir[2], Alina Rafique[3] and Muhammad Danish[4]

[1]Department of Medical Laboratory Technology, Rehman College of Allied Health Sciences, Rehman Medical Institute, Peshawar, Pakistan
[2]Department of Microbiology, Cholistan University of Veterinary and Animal Sciences, Bahawalpur, Pakistan
[3]The Institute of Molecular Biology and Biotechnology, University of Lahore, Lahore, Pakistan
[4]Rehman College of Allied Health Sciences, Rehman Medical Institute, Peshawar, Pakistan
*Corresponding author: syedsohail.edu@gmail.com

Abstract

Antimicrobial resistance (AMR) is a global health emergency transported about by the overuse and misuse of antibiotics in human medicine, agriculture, and environmental contamination. The zoonotic transmission further complicates the fight against AMR- the transfer of resistant pathogens from animals to humans. This chapter discusses some of the primary drives for AMR, including antibiotic use in agriculture, environmental contamination, and horizontal gene transfer. It delves into the zoonotic transmission pathways, direct contact with livestock, foodborne transmission, and ecological exposure, all of which add to the public health burden of AMR. Case studies included livestock-associated methicillin-resistant *Staphylococcus aureus* (LA-MRSA), multidrug-resistant *Salmonella* and *Campylobacter* in food products, and colistin-resistant *Escherichia coli* through the mcr-1-gene. The chapter emphasizes the One Health approach that encompasses human-animal environments and global strategies to reduce antibiotic use in agriculture, improve biosecurity, strengthen surveillance systems, and manage environmental contamination. There were even newer, updated data from 2020-2023 showing the influence of the COVID-19 pandemic on antibiotic use and AMR trends to show further how urgent this is. Finally, this chapter ends with recommendations for zoonotic AMR, global cooperation, tighter regulations, and antibiotic alternatives.

Keywords: Antimicrobial resistance (AMR), *Salmonella, Campylobacter, E. coli*, COVID-19, Zoonotic, Antibiotic

Cite this Article as: Ahmad SS, Nazir M, Rafique A and Danish M, 2025. Antimicrobial resistance in *Escherichia coli* in livestock; zoonotic transmission & implications for public health. In: Zaman MA, Farooqi SH and Khan AMA (eds), Holistic Health and Antimicrobial Resistance: A Zoonotic Perspective. Unique Scientific Publishers, Faisalabad, Pakistan, pp: 18-26. https://doi.org/10.47278/book.HH/2025.427

A Publication of Unique Scientific Publishers	Chapter No: 25-276	Received: 19-Jan-2025 Revised: 20-Apr-2025 Accepted: 19-May-2025

Introduction

Antimicrobial resistance (AMR) is a major worldwide health concern that compromise public health, food security, and healthcare systems. AMR occurs when bacteria, viruses, fungi, and even parasites adapt to resist the very medications that treated them so effectively earlier (Tang et al., 2023). Common infections are harder to treat, resulting in longer hospital stays, increased healthcare costs, and mortality. The World Health Organization (WHO) warns that AMR could cause up to 10 million deaths annually by the year 2050, overtaking cancer as the top killer worldwide (Todea, 2020).

Uncontrolled utilization and overuse of antibiotics in agriculture are major contributing factors to the development of AMR. Antimicrobials are used in livestock agriculture to stimulate growth and prevent disease in otherwise healthy animals, as well as to cure infections (Hosain et al., 2021). This produces an environment that promotes the survival and proliferation of resistant microbes. Another critical feature is zoonotic dissemination, in which resistant infections transmit from animals to people. Zoonotic diseases are infectious diseases that can be transmitted from animals to people via contact, food, or environmental exposure. Zoonotic antibiotic-resistant bacteria, such as *Salmonella* and *Campylobacter,* can enter humans, posing severe public health risks because drugs used in animal husbandry hinder their development (Al Sulivany et al., 2024).

The outbreak depicted in Table 1 the widespread effects on AMR, especially in agricultural systems. The indiscriminate use of antibiotics in livestock results in the emergence and spread of resistant pathogens affecting humans. For addressing AMR, the One Health approach is necessary as the health of humans, animals, and the environment is understood to be interlinked. This chapter will examine the main factors causing AMR-antibiotic use in agriculture, zoonotic transmission, and environmental contamination, as well as measures to address the global crisis of AMR through improving surveillance, policies, and sustainable agricultural practices.

1. Antimicrobial Resistance in *E. coli*

AMR, concerning *E. coli*, is the backbone of AMR research globally because the organism is present practically everywhere among humans, animals, and the environment (Snaith, 2023). This organism is so plastic, both phenotypically and genetically, that it can readily acquire and transmit resistance genes; this makes it a model organism for investigating resistance mechanisms and their use. This section discusses the genetic basis of resistance, livestock-associated patterns in *E. coli*, and evolutionary pressures on resistance.

Table 1: AMR Statistics and Outbreak Data

Outbreak	Region	Year	Key Findings	References
E. coli ESBL Outbreak	Germany	2021	Over 200 cases, 30 deaths, linked to contaminated meat products.	(Köck et al., 2021)
Multidrug-resistant *E. coli* in Poultry Farms	Southeast Asia	2023	60% of isolates carried resistance genes; >50% resistance to third-generation cephalosporins.	(Harun et al., 2024)
Colistin-resistant *E. coli* in Pig Farms	India	2022	Detected in 40% of samples, raising concerns about environmental dissemination.	(Khine et al., 2022)
Global AMR-Related Deaths	Global	2019	An estimated 4.95 million deaths are associated with bacterial AMR (The Lancet, 2022).	(Tang et al., 2023)
Antibiotic Usage in Livestock	Global	2022	>70% of medically necessary antibiotics are used in agriculture (WHO, FAO).	(Robles-Jimenez et al., 2021)

2.1 Mechanisms of Resistance in *E. coli*

At molecular and cellular levels, intrinsic and acquired mechanisms assist *E. coli* in its antibiotic resistance (Peterson & Kaur, 2018). Figure 1 shows several mechanisms, including overexpression of efflux pumps, which actively export the antibiotics from the cell, and mutations in porins that reduce entry by changing the bacterial outer membrane. In addition, lipopolysaccharide mutations lower membrane permeability and further restrict antibiotic access.

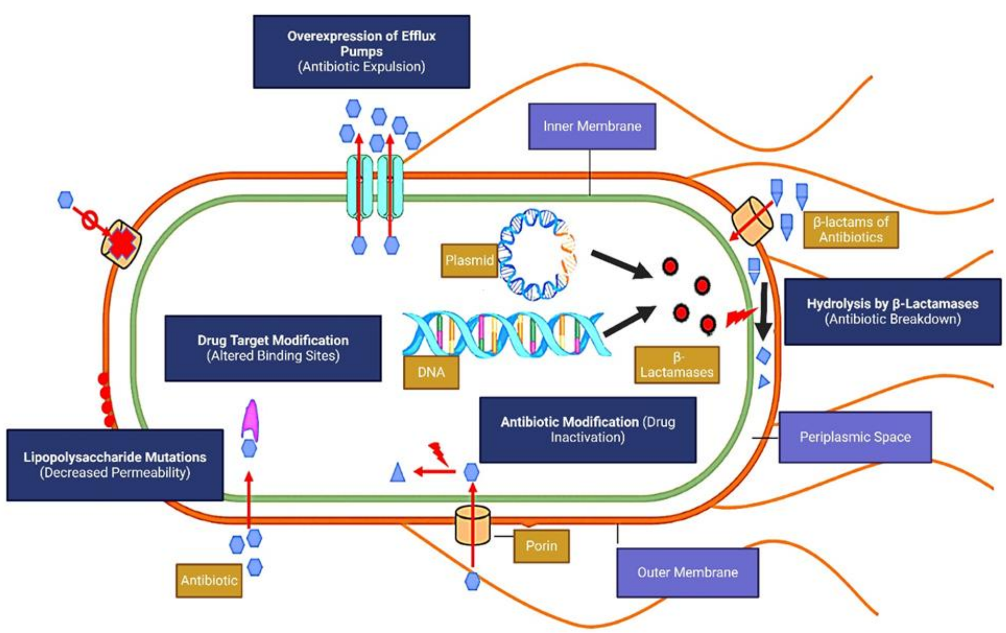

Fig. 1: Mechanisms of Bacterial Antibiotic Resistance illustrates the schematic that provides bacterial mechanisms of antibiotic resistance, which include overexpression of efflux pumps, loss of porins, mutations of lipopolysaccharides, modification of drug targets, modification of antibiotics, and hydrolysis by β-lactamases. These mechanisms act through bacterial membranes, DNA, plasmids, and enzymes.

Genetic Basis of Resistance

The movement of genetic elements such as plasmids, transposons, and integrons has triggered *E. coli* resistance. For example, plasmids carrying the blaCTX-M gene, such as the ones indicated above, are also responsible for developing resistance to extended-spectrum beta-lactams (Hussain et al., 2021). Transposons and integrons augment resistance by rearranging genes for quick adaptation. HGT, horizontal gene transfer, spreads resistance through conjugation, transformation, and transduction, which is shown in Figure 2. Livestock environments often provide very dense populations of bacteria in combination with high levels of antibiotic usage. Among such plasmids are those conjugative for the mcr-1 gene, the most memorable and looked-for, which confers resistance to colistin and was found to be present in *E. coli* strains that came from livestock, giving a serious public health issue in the future (Muloi, 2019).

Common Resistance Genes

A number of genes have been discovered to contribute significantly to *E. coli* resistance. Beta-lactam antibiotic resistance is conferred by genes such as blaCTX-M and the beta-lactamase genes, and resistance to fluoroquinolones is due to genes like qnr (Egwu et al., 2023). All these genes are frequently collocated in the same plasmid, thus affecting the efficacy of simultaneous drugs for treatment.

Horizontal Gene Transfer

Horizontal gene transfer (HGT) defines an important mechanism for the spread of resistance. Among the resistance genes shared by *E. coli* with other bacteria are those obtained through conjugation, transformation, and transduction. The importance of conjugation is relevant to livestock environments because the high densities of bacteria and the high use of antimicrobials present ideal conditions for gene exchange. Conjugative plasmids with an mcr-1 gene (conferring colistin resistance) have been isolated from livestock-associated *E. coli*. This observation raises alarming global health concerns (Bava et al., 2024).

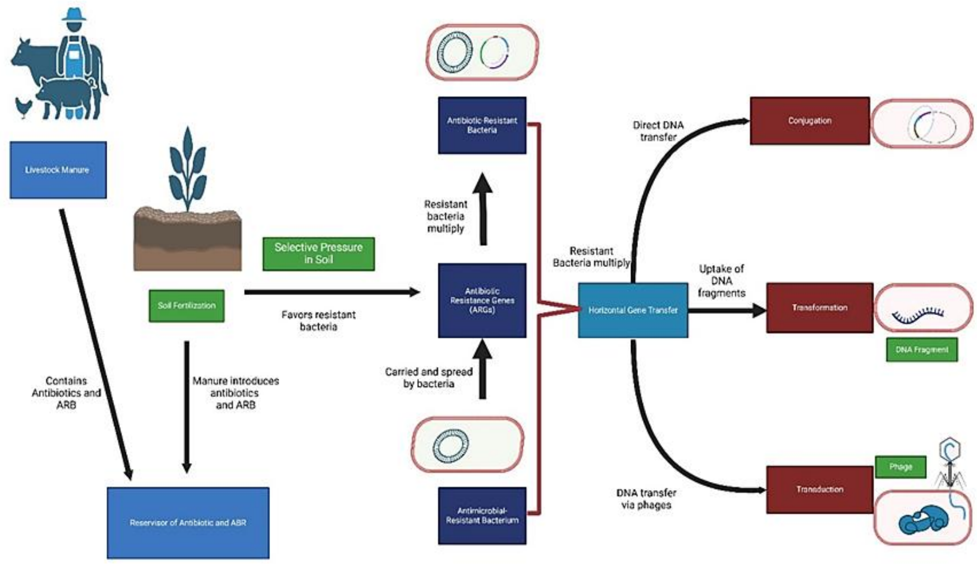

Fig. 2: Pathways of Antibiotic Resistance Spread from Livestock to the Environment illustrates that manure from farm animals introduces antibiotics and antibiotic-resistant bacteria (ARB) in organic fertilizers, thereby imparting selective pressure in soils, allowing resistant bacteria to thrive and spread. Soil serves as a key reservoir for resistance. It ensures the spread of this resistance into other environments through horizontal gene transfer mechanisms like conjugation, transformation, and transduction, thus transferring antibiotic resistance genes from one organism to the other.

2.2 Patterns of Resistance in Livestock-Associated *E. coli*

The resistance patterns of livestock-associated *E. coli* vary geographically, by livestock species, and by patterns of antimicrobial use because of the complex interrelationships that bind agriculture to bacterial evolution.

Geographical and Species-Specific Variations

Dissimilarities between regions could also be attributed to variations in the policy or practice of using antimicrobials. Thus, in Europe, tetracyclines and sulfonamides are largely resistant to pig-associated *E. coli*, while most poultry isolates from Southeast Asia are often resistant to fluoroquinolones (Renata et al., 2022). This emphasizes the need for region and livestock system-specific strategies to tackle AMR.

Antimicrobials Commonly Used in Livestock

With antibiotics such as tetracyclines, macrolides, and beta-lactams, livestock are hinged for disease prevention and growth promotion. As a result of this reliance, the resistance patterns of *E. coli* have developed. For instance, due to the widespread and intensive use of tetracyclines in poultry operations, resistance to this antibiotic exceeds 60% in poultry isolates worldwide (Hedman et al., 2020). Excessive use of these drugs creates selective pressure that favors the survival of resistant strains.

2.3 Evolutionary Pressures Driving Resistance

Combinations of anthropogenic and environmental factors play a role in the actual emergence and persistence of resistance to *E. coli*.

Selective Pressures from Antimicrobial Use in Livestock

Sub-therapeutic doses of antibiotics for growth promotion and disease prevention create tremendous selective pressure on bacterial populations, favoring the survival of resistant strains (Rahman et al., 2022). This practice has continued in many low- and middle-income countries, significantly increasing the global AMR crisis. Resistant strains from livestock cross over into human populations via food products or environmental contamination.

Environmental Factors Influencing AMR Development

AMR is aggravated by environmental contamination through livestock farming, especially through the release of antibiotic residues together with resistant bacteria into water bodies and soil. A study conducted in South Asia in 2023 demonstrated, among other results, the presence of very high concentrations of resistant *E. coli* strains in agricultural runoff, clearly indicative of the environmental dimension of AMR (Ifedinezi et al., 2024). These forms of contamination serve as reservoirs of resistance genes returning to livestock and human populations.

2. Zoonotic Transmission of Antimicrobial-Resistant *E. coli*

Zoonotic transmission of antimicrobial-resistant *E. coli* is one of the major global health threats associated with people, animals, and the environment (Olaru et al., 2023)Understanding how the pathogen transmits, its case fatalities, and the population at highest risk will assist in developing strategies for intervention and preventing its dissemination. This section discusses the critical transmission pathways, epidemiological evidence, and risk factors that heighten the threat posed by zoonotic AMR.

Routes of Transmission

AMR *E. coli* gets to human through several interconnected pathways:

1. Direct Contact: Farmers, veterinarians, and slaughter workers handle animals for purposes like maintenance or examination and hence expose one to the resistant bacteria found in animal waste, skin, and farm environment, which represent a significant occupational hazard.
2. Food Contamination: Resistant *E. coli* can enter the human food chain through improper handling or cooking of meat and via consumption of raw milk. Lastly, cross-contamination with fresh produce is also possible while processing.
3. Environmental Pathways: Introduced through agriculture runoff, inadequate waste disposal, and airborne transmissions, resistant bacteria can be found in water bodies, soil, and even municipal water sources. A study conducted in 2023 showed the presence of resistant *E. coli* in rivers near livestock farms in South Asia (Lawal et al., 2024).

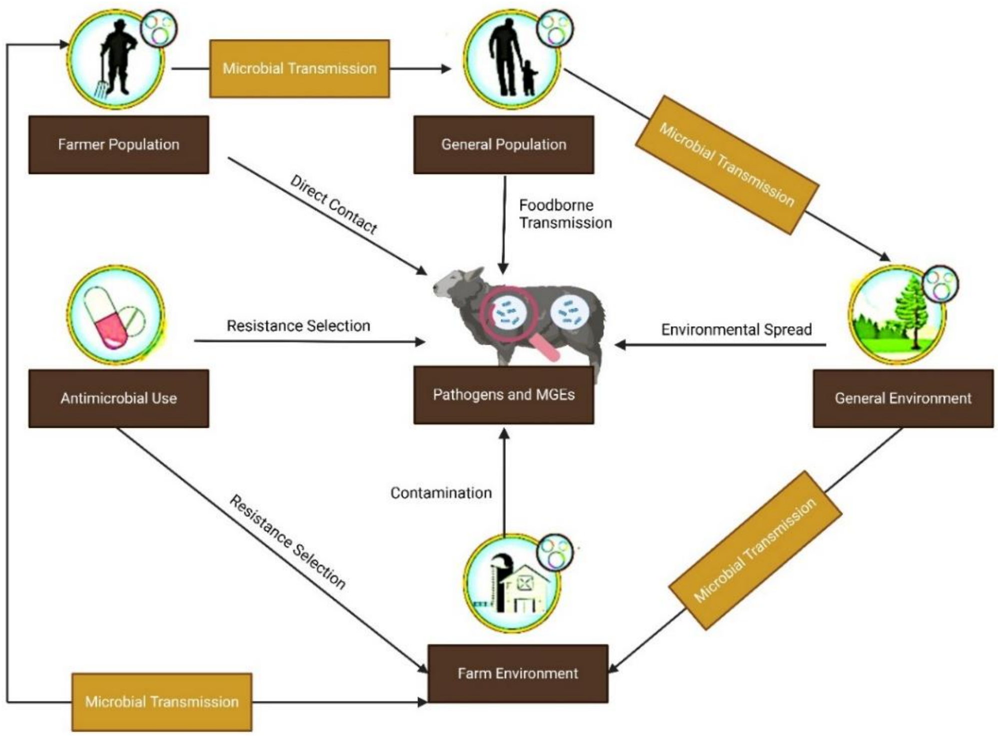

Fig. 3: Routes of Zoonotic Transmission describes the pathways of zoonotic transmission of antimicrobial resistance (AMR), showing how resistance transfers between animals, humans, and the environment. Antimicrobial usage in animals boosts resistance, propagating the resistant bacteria and mobile genetic elements (MGEs) into farms, the environment, and human populations. Major transmission routes are direct contact by farmers, foodborne contact, and environmental contamination, creating a continuum with AMR spreading in ecosystems.

3. Case Studies and Epidemiological Evidence

Well-documented evidence on zoonotic transmission is available in reports related to outbreaks and surveillance studies. For instance, a significant outbreak in 2021 in Germany caused by ESBL-producing *E. coli* in meat added more than 200 infections to the tally and caused more than 30 deaths (Avershina et al., 2021). By 2022, the WHO surveillance report revealed that nearly half of *E. coli* isolates from poultry farms were multidrug-resistant and, further, resistance patterns were almost perfectly aligned with human infections in the same region (Authority et al., 2024). These findings reaffirm the bidirectional nature of resistance transmission between humans and animals. Such case studies were of LA-MRSA, MDR *Salmonella*, and *Campylobacter*; they demonstrate that the antibiotic resistance threat is increasing (Mencía-Ares et al., 2021). LA-MRSA shows an increasing transfer from resistant bacteria found in livestock to humans, complicating treatment. MDR *Salmonella* describes resistance against foodborne pathogens, which limit treatment, and *Campylobacter* indicates how the overuse of antibiotics leads to more difficult-to-manage infections. All these cases prove the need for improving antibiotics in farm and healthcare settings to combat rising drug resistance. Table 2 below summarizes, in short, significant issues, impacts, and solutions against each of these case studies:

Table 2: Key Points of Antibiotic Resistance Case Studies

Case Study	Description	Key Issue	Impact	Solutions	References
LA-MRSA	A methicillin-resistant *S. aureus* strain in livestock spread to humans through contact, complicating treatment.	Antibiotic resistance in livestock and human transmission.	Difficult to treat, increases infection risk.	Reduce antibiotic use in farming, improve hospital infection control, and develop alternatives.	(Crespo-Piazuelo & Lawlor, 2021)
MDR Salmonella	Multi-drug-resistant *Salmonella* strains, often from contaminated food, lead to harder-to-treat infections.	Antibiotic resistance in foodborne pathogens.	Limits treatment options, severe infections.	Stricter regulations on antibiotics, better food safety, and surveillance.	(Sayed et al., 2024)
Campylobacter	Antibiotic-resistant *Campylobacter*, from overuse in farming, complicates the treatment of foodborne illness.	Antibiotic resistance in foodborne pathogens.	It is harder to treat severe cases and long-term risks.	Reduce antibiotic use, enhance food safety, and research new treatments.	(Yang et al., 2019)

1: LA-MRSA

LA-MRSA is a strain that has developed resistance against methicillin and other usual antibiotics. It is also known as *S. aureus* (Silva et al., 2023). This bacterium is usually found in livestock, like pigs and the generally associated cattle, and can be spread through direct contact with contaminated places by human beings. It is concerning because LA-MRSA is resistant to antibiotics, thus making treatment difficult and increasing the chances for severe infections, such as pneumonia or bloodstream infections. It threatens public health because it grows from rural farms to urban centers and hospitals. Thus, addressing LA-MRSA calls for a combined integrated approach of reducing antibiotics on livestock, improved infection control in healthcare settings, and alternative treatment methods such as new antibiotics or vaccinations.

2. Multi-Drug-Resistant *Salmonella*

Multi-drug-resistant *Salmonella* strains are those bacteria that have developed resistance to most antibiotics, such as tetracyclines and cephalosporins. These bacteria are transmitted mainly through food, particularly poultry products (Wu & Hulme, 2021). The problem of antibiotic resistance in *Salmonella* is a burden for public health, as it restricts the treatment options and subsequently makes the infection serious. The primary cause of this issue is the abuse of antibiotics in animal farms, particularly for the promotion of growth. There is a need for strict regulation in the use of antibiotics in food production coupled with better food safety practices and surveillance systems to track disease outbreaks if the problem of MDR *Salmonella* is to be combated.

3. Campylobacter and Antibiotic Resistance

Campylobacter is one of the primary foodborne illness pathogens, usually acquired by consuming contaminated poultry. The abuse of antibiotics in animal husbandry contributed to the emergence of antibiotic-resistant *Campylobacter* strains, complicating the treatment of very severe infections. Resistance against fluoroquinolones is especially worrying since they are antibiotics for *Campylobacter*-associated illness (Kanaan et al., 2024). Emerging antibiotic-resistant strains justify tighter regulations on antibiotic use in animal husbandry, better hygiene and food safety standards, and better education on proper cooking procedures to prevent contamination. Research into alternative treatments should also be continued to relieve the threat of resistance.

Risk Factors and Vulnerable Populations

The zoonotic transmission risk is unevenly distributed. Certain demographic groups have profoundly differential exposure and impact:
1. Occupational Risk: Individuals working directly with animals or their waste, such as farmers, veterinarians, and abattoir workers, are frequently exposed to resistant bacteria, increasing their chance of colonization or infection (Odetokun et al., 2018).
2. High-Risk Groups: Such populations can be putative high-risk populations, namely immunocompromised individuals, young children, and elderly persons, in whom the effect of resistant strains can yield grave results from infections (Vezzani et al., 2016). Resistant bacteria, such as those found in healthcare settings or contaminated food and water in community environments, are highly relevant to these populations.

4. Implications for Public Health

AMR in *E. coli* seriously compromises medical care, economic stability, and food security for public health. This section discusses AMR implications in all three settings, human, environmental, and societal-reducing the ecological boundaries of a One Health perspective to just human, animal, and environmental interactions.

4.1 Clinical Challenges

MDR *E. coli* strains have made the treatment of infections extremely difficult. The first-line antibiotics are cephalosporins and fluoroquinolones, which are becoming less and less effective. Last resort antibiotics such as carbapenems and colistin are used nowadays, making the treatment costlier, lengthening hospital stays, and increasing the mortality rate. As reported in 2023, an MDR *E. coli* bloodstream infection showed a 30% higher mortality rate than the non-resistant strains. These will, therefore, heavily burden an economic healthcare system, with a global cost estimated at more than $1.2 trillion by 2030 (Padmesh et al., 2024).

4.2 AMR and the One Health Approach

Antimicrobial resistance is one problem that best exemplifies One Health's essence. Antimicrobial-resistant strains of *E. coli* from livestock can be transmitted to people via food, direct contact, or environmental fecal contamination (Muloi et al., 2018). Integrated surveillance systems are critical for monitoring and addressing AMR. Countries like the Netherlands, with strong One Health programs, have reduced AMR prevalence through coordinated action between the veterinary, medical, and environmental sectors.

4.3 Impact on Food Safety and Security

Antimicrobial residues present a heavy risk to food safety within animal-derived products such as meat and milk. In 2022, a global study discovered that 15% of dairy samples contained detectable antibiotic residues and raised concerns about consumer health (Fatemi et al., 2024). In addition, the public concern over AMR has begun to create market shifts. Consumer awareness has forced them to demand antibiotic-free animal products, leading to changes in farming practices. However, this delicate balance must be maintained since food security using low antimicrobial use becomes even more critical in areas relying on intensive farming.

5. Strategies to Mitigate AMR in Livestock

Dealing with AMR in livestock is complex, and policy interventions with alternative methods of applying antimicrobials and reinforced biosecurity practices are required. This section investigates these strategies with attention to their potentially sustainable agricultural processes in terms of reduced AMR prevalence.

5.1 Policy Interventions

Such strong policy frameworks are necessary to curb the AMR phenomenon in livestock. Indeed, international organizations like the WHO, FAO, and the World Organisation for Animal Health (WOAH) have made animal health antimicrobial use guidelines that advocate the responsible use of antimicrobials in agriculture (Golding, 2020). These guidelines include prohibiting the use of antibiotics without veterinary oversight for growth promotion and disease prevention. Then, there are national and regional regulations, such as the ban from the European Union that banned the preventive use of antibiotics in livestock, which was enforced in 2022. This is how policy can enact sharp reductions in AMR.

5.2 Alternative Approaches to Reducing Antimicrobial Use in Livestock

Use an Innovation Alternatives that Improves Animal Health to Curb Antimicrobial Reliance in Livestock:

Probiotics and prebiotics: Enhancement of gut health and boost immunity, thereby reducing infections and antibiotic use. Add beneficial bacteria with probiotics and support them through prebiotics (Adhikari & Kim, 2017).

Phage therapy: Bacteriophage therapy uses viruses that infect specific target microorganisms (pathogenic bacteria), a more precise method of fighting infections than antibiotics without affecting the rest of the microbiome (Alsayed & Permana, 2024).

Vaccination: Vaccination can also prevent infections at the source when made specific to certain livestock diseases. Vaccines made to resist *E. coli* in poultry have reduced infection rates by 50%, which has contributed significantly to the reduction in the use of antibiotics (Śmiałek et al., 2020).

Sustainable animal health enhancing solutions to antibiotic use reduction and ideal solutions toward resolving antimicrobial resistance.

5.3 Enhancing Biosecurity and Farm Management Practices

Reducing infection risk among livestock requires efficient biosecurity measures and prevents antibiotic dependency for health maintenance. Strong hygiene protocols, regular cleaning, proper waste disposal, and controlled animal movements are essential to prevent disease outbreaks (Stull et al., 2018). These practices limit exposure to pathogens and reduce the need for antimicrobial treatments.

Monitoring and Reporting

Surveillance systems track antimicrobial use and resistance patterns, providing valuable data for proactive measures. An outstanding case in point is the Danish Integrated Antimicrobial Resistance Monitoring and Research Program (DANMAP), using transparent reporting to reduce antimicrobial resistance through data-driven interventions (Duarte et al., 2023). Strengthening biosecurity will make it less likely that a disease will be transmitted and that antimicrobials will be used, providing healthier, more sustainable avenues for farming.

6. Future Perspectives and Research Needs

Progress in combating AMR in livestock entails continued efforts to fill knowledge gaps, seize new technological opportunities, and encourage worldwide collaboration. The following sections highlight areas of importance for future research and delineate the tools and frameworks that are crucial to enhancing AMR interventions.

Emerging Technologies for AMR Detection and Monitoring

1. One Health Approach

The One Health approach, linking the health of humans, animals, and the environment, will be critical in the fight against AMR. By building joint surveillance and control systems for these sectors, we can track the spread of resistant pathogens and organize interventions together (Organization, 2019).

2. Advanced Diagnostics

Rapid and precise diagnostic tools, such as CRISPR-based and WGS, will allow more rapid detection of resistance markers, leading to earlier treatment and avoidance of unnecessary antibiotics and the spread of AMR (Govender, 2024).

3. New Antimicrobial Blood Development

Future efforts would focus on encouraging pharmaceutical research, given the slow pace at which novel antibiotic discovery proceeds. Antibiotics per se or alternative treatment methods, such as phage therapy or antimicrobial peptides, will play a significant role in managing resistant infections (Ikpe et al., 2024).

4. Global Collaboration and Policy

AMR cannot be fought without international cooperation and stronger global policy frameworks. Improved regulations on the use of antibiotics, data sharing, and joint public health strategies would prevent this problem from becoming cross-border (Coque et al., 2023).

5. Analytics Based on AI and Big Data for Predictions

The AI and machine learning technologies will utilize vast amounts of heterogeneous data generated by different sources to predict the place of trends and hotspots for AMR (Safdari et al., 2020). Having forecasted resistance patterns, these tools will then guide proactive intervention and well-targeted policy choices to control and avert outbreaks.

6. Global Network for Surveillance

Thus, the best global surveillance systems would work in real-time on AMR trends (Tacconelli et al., 2018). Honing international programs like WHO's GLASS, among others, for easy access to precise data availability and speedy response to new resistance patterns will be part of the agenda.

7. Public Awareness and Education

Public education about adequate antibiotic use has an incredible potential to slow down the AMR process (Endale et al., 2023), as well as campaigns on awareness toward the general public and professionals, educational programs for all healthcare professionals, and awareness campaigns for institutions.

8. Sustaining Agriculture

Practices in agriculture of tomorrow will become less reliant on antimicrobials as they develop alternatives such as probiotics, vaccines, and better farm management practices (Nowakiewicz et al., 2020). These methods will prevent the transmission of resistant bacteria in animals and humans.

9. Economic Investment and Innovation

An extra increase in research and diagnostics on AMR and infrastructure will be necessary to speed up the development of novel solutions (Simpkin et al., 2017). Innovative financial incentives will then spur ownership and global funding for AMR capacity-building. From these future perspectives, it is clear that a real integrated multi-sectoral, innovative, and collaborative approach to this problem would be effective and would ensure that antibiotics would be available for the benefit of future generations.

Collaborative Frameworks for Global AMR Mitigation

AMR is strong without international cooperation, one under the One Health approach. Some frameworks are:

1. Global Action Plans: Initiatives like the WHO's Global Action Plan on AMR demand joint actions across human, animal, and environmental health sectors (Organization, 2021).
2. Public-Private Partnerships: Joint models among countries, academia, and industry will be important in moving AMR research forward, receiving funding for innovations, and scaling up solutions (Boluarte & Schulze, 2022).
3. Capacity Building in LMICs: Strengthening surveillance infrastructures, training personnel, and ensuring diagnostic tools access in resource-limited settings are critical for a global response against AMR (Seale et al., 2017). Future endeavors against AMR in livestock should focus on the very critical emerging knowledge gaps, incorporate cutting-edge technologies, and stimulate international collaboration. On these conditions, researchers, policymakers, and industry actors may create a sustainable, global strategy for effective control against the spread of antimicrobial resistance.

Conclusion

Antimicrobial resistance (AMR) in Escherichia coli from livestock is a global issue that calls for action. This chapter explores the mechanisms of AMR, its prevalence in livestock, and zoonotic pathways highlighting One Health across the human-animal-environment triad. Key strategies discussed to combat AMR include policy amendments and alternatives to the traditional antimicrobials to biosecurity measures. AMR has huge health effects on populations because it threatens the treatment of diseases in clinics, raises the costs of health care, and incurs a risk to food safety. Developing solutions requires integration into One Health through guidelines, new technologies, and partnerships. An essential component of future research would be closing knowledge gaps, advancing detection, and building international collaboration. Here, stakeholders from policymakers to scientists, farmers, and consumers should come together to establish regulations, promote sustainable practices, and require responsible food production. Combating AMR is a scientific challenge and a moral imperative to ensure the future efficacy of antimicrobials and safeguard global health.

References

Adhikari, P. A., & Kim, W. K. (2017). Overview of prebiotics and probiotics: focus on performance, gut health and immunity–a review. *Annals of Animal Science*, *17*(4), 949-966.

Al Sulivany, B. S., Abdulrahman, P., Ahmed, D. Y., Naif, R. O., & Omer, E. A. (2024). Transmission of zoonotic infections (bacteria, parasites, viruses, and fungi) from aquaculture to humans and molecular methods for organism identification. *Journal of Zoonotic Diseases*, *8*(4), 580-591.

Alsayed, A. R., & Permana, A. D. (2024). Bacteriophages Therapy: Exploring Their Promising Role in Microbiome Modulation and Combatting Antibiotic Resistance. *OBM Genetics*, *8*(2), 1-8.

Authority, E. F. S., Prevention, E. C. f. D., & Control. (2024). The European Union summary report on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food in 2021–2022. *EFSA Journal*, *22*(2), e8583.

Avershina, E., Shapovalova, V., & Shipulin, G. (2021). Fighting antibiotic resistance in hospital-acquired infections: current state and emerging technologies in disease prevention, diagnostics and therapy. *Frontiers in Microbiology*, *12*, 707330.

Bava, R., Castagna, F., Lupia, C., Poerio, G., Liguori, G., Lombardi, R., Naturale, M. D., Mercuri, C., Bulotta, R. M., & Britti, D. (2024). Antimicrobial Resistance in Livestock: A Serious Threat to Public Health. *Antibiotics*, *13*(6), 551.

Boluarte, T., & Schulze, U. (2022). The case for a subscription model to tackle antimicrobial resistance. *Boston Consulting Group: Boston Consulting Group*.

Coque, T. M., Cantón, R., Pérez-Cobas, A. E., Fernández-de-Bobadilla, M. D., & Baquero, F. (2023). Antimicrobial resistance in the global health network: known unknowns and challenges for efficient responses in the 21st century. *Microorganisms*, *11*(4), 1050.

Crespo-Piazuelo, D., & Lawlor, P. G. (2021). Livestock-associated methicillin-resistant Staphylococcus aureus (LA-MRSA) prevalence in humans in close contact with animals and measures to reduce on-farm colonisation. *Irish Veterinary Journal*, *74*, 1-12.

Duarte, A. S. R., Attauabi, M., Sandberg, M., Lindegaard, M., Sönksen, U. W., & Andersen, V. D. (2023). DANMAP 2022: Use of antimicrobial

agents and occurrence of antimicrobial resistance in bacteria from food animals, food and humans in Denmark, 190.
Egwu, E., Ibiam, F., Moses, I., Iroha, C., Orji, I., Okafor-Alu, F., Eze, C., & Iroha, I. (2023). Antimicrobial susceptibility and molecular characteristics of beta-lactam-and fluoroquinolone-resistant E. coli from human clinical samples in Nigeria. *Scientific African*, *21*, e01863.
Endale, H., Mathewos, M., & Abdeta, D. (2023). Potential causes of spread of antimicrobial resistance and preventive measures in one health perspective-a review. *Infection and Drug Resistance*, 7515-7545.
Fatemi, F., Alizadeh Sani, M., Noori, S. M. A., & Hashemi, M. (2024). Status of antibiotic residues in milk and dairy products of Iran: a systematic review and meta-analysis. *Journal of Environmental Health Science and Engineering*, *22*(1), 31-51.
Golding, S. E. (2020). *Exploring antimicrobial stewardship in UK veterinary medicine and livestock agriculture: a mixed-method, one health approach* University of Surrey]. https://doi.org/10.15126/thesis.00853545
Govender, K. N. (2024). *Metagenomic sequencing directly from blood culture as a tool for clinical diagnosis* University of Oxford]. 10.5287/ora-b79z9azdb
Harun, A. B., Khatri, B., & Karim, M. R. (2024). Phenotypic and genotypic pattern of antimicrobial resistance in livestock and poultry in South Asia: A systematic review and meta-analysis. *Food Control*, 110575.
Hedman, H. D., Vasco, K. A., & Zhang, L. (2020). A review of antimicrobial resistance in poultry farming within low-resource settings. *Animals*, *10*(8), 1264.
Hosain, M. Z., Kabir, S. L., & Kamal, M. M. (2021). Antimicrobial uses for livestock production in developing countries. *Veterinary World*, *14*(1), 210.
Hussain, H. I., Aqib, A. I., Seleem, M. N., Shabbir, M. A., Hao, H., Iqbal, Z., Kulyar, M. F.-e.-A., Zaheer, T., & Li, K. (2021). Genetic basis of molecular mechanisms in β-lactam resistant gram-negative bacteria. *Microbial Pathogenesis*, *158*, 105040.
Ifedinezi, O. V., Nnaji, N. D., Anumudu, C. K., Ekwueme, C. T., Uhegwu, C. C., Ihenetu, F. C., Obioha, P., Simon, B. O., Ezechukwu, P. S., & Onyeaka, H. (2024). Environmental antimicrobial resistance: implications for food safety and public health. *Antibiotics*, *13*(11), 1087.
Ikpe, F., Williams, T., Orok, E., & Ikpe, A. (2024). Antimicrobial resistance: use of phage therapy in the management of resistant infections. *Molecular Biology Reports*, *51*(1), 925.
Kanaan, M. H. G., Mohammed, F. A., & Abdullah, S. S. (2024). Prevalence patterns, virulence indices, and antibiotics resistance in Campylobacter. *Journal of Applied Pharmaceutical Science*.
Khine, N. O., Lugsomya, K., Niyomtham, W., Pongpan, T., Hampson, D. J., & Prapasarakul, N. (2022). Longitudinal monitoring reveals persistence of colistin-resistant Escherichia coli on a pig farm following cessation of colistin use. *Frontiers in veterinary science*, *9*, 845746.
Köck, R., Herr, C., Kreienbrock, L., Schwarz, S., Tenhagen, B.-A., & Walther, B. (2021). Multiresistant Gram-Negative Pathogens: A Zoonotic Problem. *Deutsches Ärzteblatt International*, *118*(35-36), 579.
Lawal, H., Aklilu, E., Kamaruzzaman, N. F., Suhaili, Z., Sani, G. M., & Lemlem, M. (2024). Livestock and environment as potential sources and reservoirs for multi-drug resistant Escherichia coli in Malaysia: A Systematic Review: 2024.028. *Veterinary Integrative Sciences*, *22*(2). https://doi. org/10.12982/VIS.
Mencía-Ares, O., Argüello, H., Puente, H., Gómez-García, M., Álvarez-Ordóñez, A., Manzanilla, E. G., Carvajal, A., & Rubio, P. (2021). Effect of antimicrobial use and production system on Campylobacter spp., Staphylococcus spp. and Salmonella spp. resistance in Spanish swine: A cross-sectional study. *Zoonoses and Public Health*, *68*(1), 54-66.
Muloi, D., Ward, M. J., Pedersen, A. B., Fevre, E. M., Woolhouse, M. E., & van Bunnik, B. A. (2018). Are food animals responsible for transfer of antimicrobial-resistant Escherichia coli or their resistance determinants to human populations? A systematic review. *Foodborne Pathogens and Disease*, *15*(8), 467-474.
Muloi, D. M. (2019). *Epidemiology of antimicrobial resistance at the livestock-human interface in an urban environment: a One Health approach* University of Edinburgh].
Nowakiewicz, A., Zięba, P., Gnat, S., & Matuszewski, Ł. (2020). Last call for replacement of antimicrobials in animal production: modern challenges, opportunities, and potential solutions. *Antibiotics*, *9*(12), 883.
Odetokun, I. A., Ballhausen, B., Adetunji, V. O., Ghali-Mohammed, I., Adelowo, M. T., Adetunji, S. A., & Fetsch, A. (2018). Staphylococcus aureus in two municipal abattoirs in Nigeria: Risk perception, spread and public health implications. *Veterinary Microbiology*, *216*, 52-59.
Olaru, I. D., Walther, B., & Schaumburg, F. (2023). Zoonotic sources and the spread of antimicrobial resistance from the perspective of low and middle-income countries. *Infectious Diseases of Poverty*, *12*(03), 73-87.
Organization, W. H. (2019). *Turning plans into action for antimicrobial resistance (AMR): working paper 2.0: implementation and coordination*. https://coilink.org/20.500.12592/s7k1xt
Organization, W. H. (2021). *Antimicrobial resistance and the United Nations sustainable development cooperation framework: Guidance for United Nations Country teams*. World Health Organization.
Padmesh, S., Singh, A., Chopra, S., Sen, M., Habib, S., Shrivastava, D., & Johri, P. (2024). Isolation and characterization of novel lytic bacteriophages that infect multi drug resistant clinical strains of Escherichia coli. *Environmental Science and Pollution Research*, *31*(46), 57327-57337.
Peterson, E., & Kaur, P. (2018). Antibiotic resistance mechanisms in bacteria: relationships between resistance determinants of antibiotic producers, environmental bacteria, and clinical pathogens. *Frontiers in Microbiology*, *9*, 2928.
Rahman, M. R. T., Fliss, I., & Biron, E. (2022). Insights in the development and uses of alternatives to antibiotic growth promoters in poultry and swine production. *Antibiotics*, *11*(6), 766.
Urban-Chmiel, R., Marek, A., Stępień-Pyśniak, D., Wieczorek, K., Dec, M., Nowaczek, A., & Osek, J. (2022). Antibiotic resistance in bacteria—A review. *Antibiotics*, *11*(8), 1079.
Robles-Jimenez, L. E., Aranda-Aguirre, E., Castelan-Ortega, O. A., Shettino-Bermudez, B. S., Ortiz-Salinas, R., Miranda, M., Li, X., Angeles-

Hernandez, J. C., Vargas-Bello-Pérez, E., & Gonzalez-Ronquillo, M. (2021). Worldwide traceability of antibiotic residues from livestock in wastewater and soil: A systematic review. *Animals*, *12*(1), 60.

Safdari, R., GhaziSaeedi, M., Masoumi-Asl, H., Rezaei-Hachesu, P., Mirnia, K., & Samad-Soltani, T. (2020). Knowledge discovery and visualization in antimicrobial resistance surveillance systems: a scoping review. *Artificial Intelligence Review*, *53*, 369-406.

Sayed, F., Kaur, R., Jha, V., & Quraishi, U. A. (2024). Prevalence, Antibiotic Resistance, and Implications for Public Health Due to Salmonella Contamination in Food Products. *South Asian Journal of Research in Microbiology*, *18*(5), 18-29.

Seale, A. C., Hutchison, C., Fernandes, S., Stoesser, N., Kelly, H., Lowe, B., Turner, P., Hanson, K., Chandler, C. I., & Goodman, C. (2017). Supporting surveillance capacity for antimicrobial resistance: laboratory capacity strengthening for drug resistant infections in low and middle income countries. *Wellcome Open Research*, *2*.

Silva, V., Araújo, S., Monteiro, A., Eira, J., Pereira, J. E., Maltez, L., Igrejas, G., Lemsaddek, T. S., & Poeta, P. (2023). Staphylococcus aureus and MRSA in livestock: antimicrobial resistance and genetic lineages. *Microorganisms*, *11*(1), 124.

Simpkin, V. L., Renwick, M. J., Kelly, R., & Mossialos, E. (2017). Incentivising innovation in antibiotic drug discovery and development: progress, challenges and next steps. *The Journal of Antibiotics*, *70*(12), 1087-1096.

Śmiałek, M., Kowalczyk, J., & Koncicki, A. (2020). Influence of vaccination of broiler chickens against Escherichia coli with live attenuated vaccine on general properties of E. coli population, IBV vaccination efficiency, and production parameters—A field experiment. *Poultry Science*, *99*(11), 5452-5460.

Snaith, A. E. (2023). *A study of colonisation of the human gastrointestinal tract by multidrug resistant Escherichia coli* University of Birmingham]. https://etheses.bham.ac.uk/id/eprint/14157/

Stull, J. W., Bjorvik, E., Bub, J., Dvorak, G., Petersen, C., & Troyer, H. L. (2018). 2018 AAHA infection control, prevention, and biosecurity guidelines. *Journal of the American Animal Hospital Association*, *54*(6), 297-326.

Tacconelli, E., Sifakis, F., Harbarth, S., Schrijver, R., van Mourik, M., Voss, A., Sharland, M., Rajendran, N. B., Rodríguez-Baño, J., & Bielicki, J. (2018). Surveillance for control of antimicrobial resistance. *The Lancet Infectious Diseases*, *18*(3), e99-e106.

Tang, K. W. K., Millar, B. C., & Moore, J. E. (2023). Antimicrobial resistance (AMR). *British Journal of Biomedical Science*, *80*, 11387.

Todea, A. (2020). A Study of Consumer Perception of Antibiotic Resistance and Antibiotic Use in Ireland. https://doi.org/10.21427/bfp1-5v68

Vezzani, A., Fujinami, R. S., White, H. S., Preux, P.-M., Blümcke, I., Sander, J. W., & Löscher, W. (2016). Infections, inflammation and epilepsy. *Acta Neuropathologica*, *131*, 211-234.

Wu, S., & Hulme, J. P. (2021). Recent advances in the detection of antibiotic and multi-drug resistant salmonella: An update. *International Journal of Molecular Sciences*, *22*(7), 3499.

Yang, Y., Feye, K. M., Shi, Z., Pavlidis, H. O., Kogut, M., J. Ashworth, A., & Ricke, S. C. (2019). A historical review on antibiotic resistance of foodborne Campylobacter. *Frontiers in Microbiology*, *10*, 1509.