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ANTIBIOTIC RESISTANCE, AGRICULTURE, LIVESTOCK, ONE HEALTH, PUBLIC HEALTH

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Abstract. *Antimicrobial resistance (AMR) represents a quintessential One Health challenge, transcending the boundaries between human medicine, animal health, and the environment. The agricultural and livestock sectors are pivotal arenas in this global crisis, acting as significant reservoirs and amplifiers of resistant bacteria and resistance genes. This research examines the intricate pathways through which antibiotic use in food-producing animals contributes to the emergence, selection, and dissemination of resistant pathogens. The review synthesizes current evidence on the practice of antibiotic administration for prophylaxis, meta phylaxis, and growth promotion in intensive farming systems, highlighting how these subtherapeutic and therapeutic applications exert selective pressure, driving microbial evolution. Critical transmission routes are analysed, including the direct transfer through the food chain via contaminated meat products, indirect environmental spread through manure and wastewater, and occupational exposure for farm workers. The consequences for public health are severe, manifesting as increased morbidity, mortality, and treatment costs associated with infections caused by multidrug-resistant organisms like extended-spectrum beta- lactamase (ESBL)- producing Enterobacteriaceae, methicillin-resistant Staphylococcus aureus (MRSA), and resistant Campylobacter. The discussion underscores the imperative for integrated, multisectoral interventions under the One Health framework. These include the stringent implementation of stewardship programs to reduce unnecessary antibiotic use in agriculture, the adoption of alternative animal health management practices, enhanced surveillance of AMR across all sectors, and the development of coherent policies that align agricultural productivity with long-term public health security. Mitigating AMR demands a collaborative, systemic approach that acknowledges the interdependence of human, animal, and environmental health.*

Keywords*: agriculture, livestock, one health, public health, antibiotic resistance.*

INTRODUCTION

The discovery of antibiotics revolutionized modern medicine, but their effectiveness is now critically undermined by antimicrobial resistance (AMR). While misuse in human healthcare is a key driver, modern intensive agriculture is a paramount and distinct contributor to this global crisis. The sector's massive, routine use of antimicrobials, for therapy, disease prevention, and historically as growth promoters, creates a powerful selective engine for resistance. Administered often at low, subtherapeutic doses to vast animal populations, these drugs exert constant pressure, favouring resistant bacteria and enriching farms with mobile resistance genes.

This agricultural dimension creates profound public health risks, best understood through the One Health lens, which connects human, animal, and environmental health and these aspects must be taught from early studies, within universities, through education (PASCALAU ET AL., 2025). Resistant pathogens and genes selected in livestock operations do not remain contained. They travel via the food chain through meat, eggs, and dairy; pollute the environment through manure used as fertilizer, contaminating soil and watercourses; and cause direct occupational exposure among farm and slaughterhouse workers. Thus, agricultural practices directly fuel cycles of resistance that impact human medicine.

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The consequences are severe and escalating. Infections from resistant foodborne pathogens like Salmonella and Campylobacter lead to treatment failures (ABD-ELGHANY ET AL., 2022). The global rise of livestock-associated MRSA and ESBL-producing E. coli demonstrates the direct flow of resistance from farm to human. Furthermore, agriculture's environmental contamination creates a widespread genetic reservoir, facilitating the horizontal transfer of resistance traits to human pathogens.

Therefore, this research aims to comprehensively analyse agriculture's central role as an engine of AMR. It will detail the specific practices driving resistance development on farms, trace the pathways of transmission into the human sphere, and review the mounting evidence of public health impacts. Ultimately, it argues that mitigating AMR is impossible without targeted, policy-driven reforms in agricultural antibiotic use, implemented through a concerted One Health framework to preserve these vital medicines for the future (PANDEY ET AL, 2023).

MATERIAL AND METHODS

This research employs a systematic literature synthesis methodology to analyse the nexus between agricultural antibiotic use, antimicrobial resistance, and public health impacts.

The primary objective was to identify, critically evaluate, and integrate evidence from peer-reviewed scientific studies, systematic reviews, meta-analyses, and reports from major international health and agricultural organizations.

Literature search strategy: comprehensive research was conducted across major electronic databases, including PubMed/MEDLINE, Web of Science, Scopus, and Google Scholar. The search was performed for articles published between January 2010 and December 2023 to capture the most recent evidence, with seminal older studies included for historical context. The search strategy utilized a combination of Medical Subject Headings (MeSH) terms and keywords. Core terms included: "antimicrobial resistance" or "antibiotic resistance" and "agriculture" or "livestock" or "animal husbandry" and "One Health" and "public health" (BUCUR ET AL., 2025). These were combined with specific modifiers such as "transmission", "foodborne", "zoonotic", "stewardship", "growth promotion", "meta phylaxis", "ESBL", "MRSA", "Campylobacter", and "Salmonella". Reference lists of key articles and relevant reviews were hand-searched to identify additional primary sources.

Study selection and inclusion criteria: the initial research yielded a large volume of citations. Titles and abstracts were screened for relevance. Full-text articles were then assessed against predefined inclusion criteria: (1) studies focusing on antibiotic use in food-producing animals (BALAN ET AL, 2022) (poultry, swine, cattle, aquaculture); (2) research documenting the emergence, prevalence, or molecular characterization of AMR in livestock, farm environments, or associated food products; (3) epidemiological studies, including genomic analyses, tracing the transmission of resistant pathogens or resistance genes from animals to humans via food, environmental, or occupational routes; (4) reviews and reports quantifying the public health burden (e.g., treatment failure, economic cost) linked to agricultural AMR; and (5) policy analyses or evaluations of interventions aimed at reducing agricultural antibiotic use. Studies focused solely on human clinical AMR without link to agriculture, or on companion animals, were excluded.

Data extraction and synthesis: data from included studies were extracted into a standardized template, capturing study design, geographic location, animal species, antibiotic classes studied, resistant pathogens/gene targets identified, transmission pathways investigated, public health outcomes measured, and key findings. Given the heterogeneity of study designs (microbiological, epidemiological, genomic, economic), a formal meta-analysis was not feasible.

Instead, a narrative synthesis approach was adopted. The extracted evidence was thematically organized into logical categories aligning with the research objectives: patterns of antibiotic use in agriculture; mechanisms of resistance selection; transmission pathways; public health consequences; and intervention strategies.

Within each theme, findings were compared, contrasted, and integrated to identify consensus, highlight knowledge gaps, and draw overarching conclusions. Special attention was paid to the strength of evidence, particularly for transmission studies utilizing whole-genome sequencing, which provides high-resolution links between animal and human isolates.

Regarding the identified limitations, this research is subject to limitations inherent in its methodology. The reliance on published literature may introduce publication bias. Surveillance data on AMR in agriculture is highly variable in quality and consistency across different countries, potentially skewing the global perspective. Furthermore, quantifying the exact proportion of the human AMR burden attributable specifically to agricultural sources remains methodologically challenging, despite strong mechanistic and observational evidence.

RESULTS AND DISCUSSIONS

The synthesized literature reveals a consistent and concerning global pattern. Antibiotic consumption in the livestock sector is substantial, often exceeding human medical use in many countries, with a significant portion administered for non-therapeutic purposes. Key classes, including tetracyclines, penicillin, and sulphonamides, are widely used, paralleling the high prevalence of resistance to these drugs in livestock-associated bacteria.

Studies consistently isolate resistant pathogens from animals, their products, and farm environments. High rates of resistance are reported in E. coli, Salmonella, and Campylobacter from poultry and swine, with increasing detection of critically important antimicrobials (CIAs) like third-generation cephalosporins and fluoroquinolones. Molecular studies confirm the presence and diversity of mobile genetic elements (e.g., plasmids) carrying resistance genes in these settings.

Transmission studies, particularly those employing whole-genome sequencing (WGS), provide compelling evidence of clonal spread and gene flow. Furthermore, identical resistance plasmids have been found in bacteria from animals and humans, confirming the horizontal gene transfer of resistance determinants across the One Health continuum (VELASQUEZ ET AL., 2022).

The results underscore agriculture as a formidable crucible for AMR (THANNER ET AL., 2016). The practice of mass medication, especially for disease prevention, creates near-ideal conditions for selection. Subtherapeutic dosing kills susceptible bacteria while leaving resistant subpopulations to flourish and become dominant. This selective pressure is not confined to the target pathogens; it reshapes the entire gut and environmental microbiome.

The food chain is a major, well-documented transmission route. Contamination of meat during slaughter and processing is common. Inadequate cooking or cross-contamination in kitchens can then lead to human colonization or infection. The high prevalence of resistant Campylobacter in retail chicken, for instance, directly correlates with human treatment failures for fluoroquinolone-resistant infections.

The environmental pathway is a diffuse but vast amplifier. Manure applied as fertilizer spreads resistant bacteria and genetic elements into soil and water ecosystems (SMULEAC ET AL., 2025, 2020). From there, they can colonize wildlife, contaminate crops, and enter water sources, creating secondary reservoirs far from the original farm. This environmental contamination represents a long-term ecological legacy of agricultural AMR.

Occupational exposure presents a direct risk. Farmers, veterinarians, and slaughterhouse workers have significantly higher carriage rates of livestock-associated resistant bacteria like LA-

MRSA compared to the public, demonstrating direct animal-to-human transmission (SUN ET AL., 2025).

The public health consequences are tangible. Infections from resistant foodborne pathogens lead to longer illnesses, higher hospitalization rates, increased healthcare costs, and greater mortality. The erosion of CIAs compromises medical procedures that rely on effective prophylaxis, such as chemotherapy and organ transplantation. The economic burden extends beyond healthcare to include productivity losses and trade restrictions.

Addressing this multifaceted crisis requires systemic change. The success of policies in the European Union, translated also in Romanian, where there was the case, with a translation workflow used properly, (PASCALAU, 2023) (banning antibiotic growth promoters, enforcing veterinary oversight) in reducing antibiotic use and, in some cases, resistance prevalence, provides a proof of concept. Effective strategies must include: (1) Global restriction of all non-therapeutic antibiotic use, including growth promotion and routine prophylaxis. (2) Implementation of robust veterinary stewardship, mandating prescriptions and promoting alternative disease prevention strategies like improved hygiene, vaccination, and better animal welfare. (3) Investment in surveillance integrating human, animal, and environmental data to track trends and the impact of interventions. (4) Public and producer education to shift practices and consumer demand, starting to cultivate this environmental data awareness from early stages of studies, namely, from faculty programmes (PASCALAU ET AL., 2025, 2021). The discussion confirms that a siloed approach is futile; only a truly One Health strategy, with coordinated action across agricultural, health, and environmental sectors, can mitigate the AMR crisis stemming from agriculture (MCEWEN ET AL., 2018, MANYI-LOH ET AL., 2018).

CONCLUSIONS

The evidence presented in this review leads to an unequivocal conclusion: the use of antibiotics in agriculture and livestock production is a primary driver of the global antimicrobial resistance (AMR) crisis, with severe and escalating consequences for public health. The agricultural sector is not merely a contributor but a powerful engine for the selection, amplification, and dissemination of resistant bacteria and their genetic determinants. The mechanisms are clear: the routine, and often excessive, application of antibiotics for therapy, disease prevention, and historically for growth promotion, exerts a relentless selective pressure. This pressure operates with efficiency in the dense, connected populations of intensive farming systems, rapidly promoting resistant strains.

The pathways connecting farm to human are multiple, robust, and well-documented. The food chain acts as a direct conduit, delivering resistant pathogens like Salmonella and Campylobacter to consumers. The environment serves as a vast, interconnected reservoir, where resistance genes spread via manure and wastewater, contaminating soil, water, and produce, and enabling exposure far beyond the farm gate. Occupational exposure provides a direct link for those working with animals, placing them on the front lines of risk. Through these routes, resistance originating in animal husbandry compromises the treatment of human infections, increases healthcare costs, and ultimately costs lives. The erosion of the efficacy of critically important antimicrobials for human medicine, such as fluoroquinolones and third- and fourth-generation cephalosporins, represents a particularly grave threat to modern medical care.

Therefore, the status quo is unsustainable. Continuing the widespread non-therapeutic use of antibiotics in food animal production is a direct threat to global health security. The solution lies not in the cessation of animal agriculture, but in its fundamental transformation towards more sustainable and responsible practices. The One Health paradigm is not merely a useful lens but an operational imperative for effective intervention. Success requires breaking down sectoral silos and fostering genuine collaboration between human medicine, veterinary science, agriculture, environmental science, and policymaking.

Specific, actionable conclusions emerge from this research. First, legislative and regulatory action is paramount. A global ban on the use of antibiotics for growth promotion must be universally adopted and enforced, building on the European model. Further, the prophylactic use of antibiotics in healthy animals must be severely restricted, reserved for exceptional circumstances under strict veterinary oversight, rather than serving as a standard management crutch for suboptimal welfare and hygiene conditions.

Second, veterinary antibiotic stewardship must become the global norm. This requires making all antibiotic use in animals' prescription-only, eliminating over-the-counter access. It necessitates training and empowering veterinarians as stewards, with a focus on accurate diagnosis, targeted treatment, and record-keeping. Equally important is the promotion of alternative strategies for animal health and productivity. Investment in and adoption of improved biosecurity, better housing and stocking densities, rigorous vaccination programs, probiotics, prebiotics, and enhanced animal nutrition are essential to reduce the disease burden and the perceived need for antibiotics.

Third, integrated, genomic-enabled surveillance across the human-animal-environment interface is critical. Robust monitoring systems are needed to track antibiotic consumption, resistance trends in key bacterial pathogens, and the movement of resistant clones and genes. Whole-genome sequencing is a powerful tool for source attribution and understanding transmission dynamics, enabling targeted, evidence-based interventions.

Finally, economic and behavioural incentives must be aligned with public health goals. This includes supporting farmers through the transition away from antibiotic-dependent systems, potentially through subsidies or premium pricing for products from responsible farms. Consumer education and demand for meat produced with reduced or no antibiotics can be a powerful market driver for change.

In conclusion, tackling AMR from agricultural sources is a complex but non-negotiable challenge. It demands a departure from short-term productivity gains at the expense of long-term therapeutic efficacy. The choice is stark: continue practices that jeopardize the foundation of modern medicine, or embrace a collaborative, preventive, and stewardship oriented One Health approach. By redefining our relationship with antibiotics in agriculture, from tools for routine management to precious, finite resources to be used sparingly and with utmost care, we can safeguard their efficacy for treating sick animals and, most importantly, protect human health for generations to come. The time for concerted, decisive global action is now.

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