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Antibiotic Residues in Poultry Products: Public Health Risks, Antimicrobial Resistance, and Sustainable Alternatives

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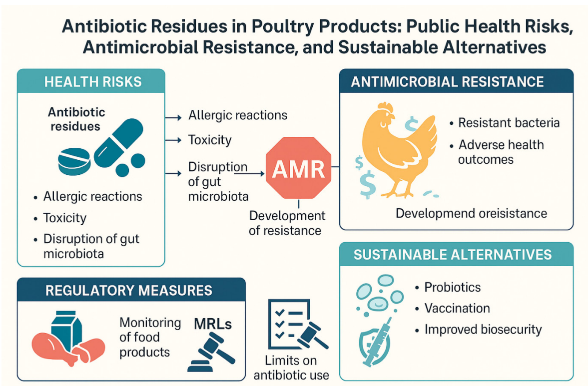

Abstract

The presence of antibiotic residues in poultry-derived food products presents a serious public health concern and contributes significantly to the escalating global issue of Antimicrobial Resistance (AMR). This review explores the health hazards associated with these residues, emphasizing how the routine operation of antibiotics in poultry farming primarily for growth enhancement and disease prevention leads to the persistence of drug residues in meat and eggs. Such residues have been linked to a range of adverse effects in consumers, including allergic reactions, toxicological impacts, disturbances to gut microbiota, and, critically, the emergence and spread of antibiotic-resistant bacteria. Nominally, long-term exposure can intensify these risks, posing challenges not only to individual well-being but also to the integrity of public health systems. To ensure food safety, regulatory measures such as setting Maximum Residue Limits (MRLs) and implementing rigorous monitoring systems are essential. Nevertheless, the continued reliance on antibiotics in poultry production underscores the urgent need for alternative approaches that sustain animal health without contributing to AMR. Key strategies include enhancing public awareness, promoting responsible antibiotic use through antimicrobial management, and adopting sustainable agricultural practices. Combating AMR demands a unified, global response involving collaborative efforts from policymakers, farmers, veterinarians, and healthcare professionals. Looking forward, research must focus on developing safer therapeutic alternatives and innovative, antibiotic-free farming methods to significantly reduce the prevalence of residues in poultry products.

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Introduction

Poultry farming is a vital component of global agriculture, serving as a key provider of excellent high-protein. It offers an ecological means of assembling the increasing need for protein while minimizing the carbon footprint typically associated with livestock production [13,18]. However, to maintain flock health and improve productivity, poultry operations frequently rely on antibiotics not only for medicinal purposes but also for growth promotion and disease prevention. This widespread use, particularly at sub medicinal levels, has raised significant concerns about food safety and public health. Antibiotics including amoxicillin and oxytetracycline are commonly provided to enhance feed efficiency and weight gain in poultry [1,42,52]. Yet, their continued use has been implicated in the development of Antibiotic-Resistant Bacteria (ARB), which can be transferred to humans via the food chain or environmental exposure pathways [59,72].

A growing body of evidence indicates that antibiotic residues often remain in poultry products meat and eggs if appropriate withdrawal periods are not observed prior to slaughter. These residues can stimulate allergic reactions, disrupt the gut microbiome, and contribute to the growth of AMR [2,14,47]. AMR has emerged as one of the most critical threats to global public health, compromising the effectiveness of antibiotic therapies and increasing the burden on healthcare systems. The consumption of foods containing antibiotic residues facilitates the transmission of resistant strains to humans, compounding the challenge [12,55,64].

The extent and patterns of antibiotic usage in broiler production differ considerably cross-boundary, concerned by regulatory structures, economic incentives, and farmers' access to veterinary expertise [57]. In many settings, antibiotics are dispensed without proper veterinary guidance, often resulting in misuse and overuse [15,54]. This lack of oversight accelerates the emergence of resistant bacterial strains, thereby heightening risks to both animal and human health [30,81].

Beyond individual health consequences, the implications of antibiotic misuse in poultry farming extend to broader societal and environmental levels. The proliferation of multidrug-resistant bacteria diminishes available treatment options for human infections and imposes a significant economic burden on health systems [4,64]. Furthermore, antibiotic residues introduced into the environment especially through poultry manure used as fertilizer can promote the spread of resistance genes among environmental microbiota [20]. Recognizing this, the WHO has called for organized, multisectoral responses to antimicrobial resistance, with a strong emphasis on the food production sector [59].

This review critically examines the issues surrounding antibiotic use in poultry farming, focusing on the types of antibiotics used, the pathways of remains accumulation, and current regulatory frameworks. It explores the health risks posed by antimicrobial residues, particularly the surge of AMR, and discusses the importance of surveillance, consumer education, and policy reform. Additionally, the paper presents guidance for mitigating public problems, emphasizing alternative approaches to antibiotic application and sustainable farming practices.

Antibiotics used as growth promoter's mechanisms in livestock farming

The presence of antimicrobial residues in domestic fowl-derived food items poses a exceptional threat to both environmental health and food security. In poultry farming, antibiotics are routinely employed for medicinal treatment, growth enhancement, and disease prevention. However, the widespread and often indiscriminate use of these drugs increases the likelihood that residual traces persist in meat and eggs. Such residues can adversely affect human health, potentially triggering allergic reactions and contributing to the emergence of antibiotic-resistant bacterial strains [1,34,54]. The accumulation of antibiotic residues is influenced by a complex interplay of factors, including the specific kind of antimicrobial administered, the route of administration, dosage, withdrawal periods, and overall farm management practices (see Table 1).

Table 1: Factors influencing antibiotic residue accumulation in poultry products.

Category	Details	Implications
Common antibiotics	Tetracyclines (oxytetracycline), Penicillins (amoxicillin), Sulfonamides, Fluoroquinolones (enrofloxacin), Macrolides, etc.	Vary in persistence; fluoroquinolones and aminoglycosides tend to be more residue prone.
Routes of administration	Feed: Mass medication via feed. Water: Dissolved in drinking water. Injection: Intramuscular or subcutaneous delivery.	Continuous exposure (feed/water); localized residues (injection); risk of inconsistent dosing.
Dosage and duration	Higher doses and prolonged use without vet oversight increase the risk of residue accumulation.	Accumulation of unmetabolized antibiotics in tissues; potential for MRL violations.
Withdrawal period compliance	The time needed for antibiotic clearance before slaughter or egg collection.	Non-compliance is a leading cause of violative residue levels in meat and eggs.
Farming practices	Intensive Systems: Routine antibiotic use. Extensive Systems: Lower use but risk of unregulated treatment.	Intensive systems have higher residue risks; poor record-keeping can hinder withdrawal tracking.
Health status of birds	Illness or stress can impair drug metabolism and excretion.	Leads to slower antibiotic clearance and increased residue retention.
Processing & storage	Processing: Washing, freezing, cutting	Minimal impact on residues; does not degrade many antibiotics.
	Storage: Refrigeration or freezing	
Cooking practices	High-heat cooking (boiling, grilling) Undercooking or light cooking	Heat can degrade some antibiotics (tetracyclines); others (fluoroquinolones) may persist.

While the judicious use of certain antibiotics in poultry farming is important for maintaining flock health and preventing disease, the persistence of drug residues in domesticated birds' product (meat or eggs) presents a notable risk to public health. Frequently used antibiotic classes in poultry farming involve fluoroquinolones, tetracyclines and sulfonamides valued for their effectiveness in promoting growth and reducing the incidence of infections within flocks [2]. However, improper practices such as off-label usage, overuse, and neglecting the recommended withdrawal periods before slaughter or egg collection significantly elevate the risk of residual contamination in food products [36]. Numerous studies have reported that a considerable proportion of poultry products on the market encompass noticeable levels of antibiotic residues, emphasizing the critical necessity for robust regulatory monitoring enforcement [81].

A variety of factors influence the extent to which residues remain in edible poultry products. These include the specific antibiotic used, dosage levels, duration of treatment, and most crucially, compliance with withdrawal periods [8,56]. Additionally, practices such as administering medicated feed or water can contribute to continual exposure, increasing residue retention. In many regions, inadequate regulation and the widespread use of veterinary drugs without proper oversight often termed extra-label use further compound this issue [44]. Environmental conditions, including contaminated feed and poor storage practices, can also irritate residue accumulation by compromising the integrity of the production chain [60].

Antibiotics are administered to domestic fowl through several approach, comprising incorporation in feed and water, or by injection [61]. Each method presents distinct implications for residue buildup. Feed and water are the most prevalent delivery systems, often resulting in prolonged, low-dose exposure that contributes to residue formation in tissues and eggs [36]. Injections, though less commonly used, can lead to localized accumulation of residues at injection sites if proper dosage and withdrawal protocols are not followed. Therefore, the route of administration plays a key role in determining the residual profile of antibiotics within poultry products.

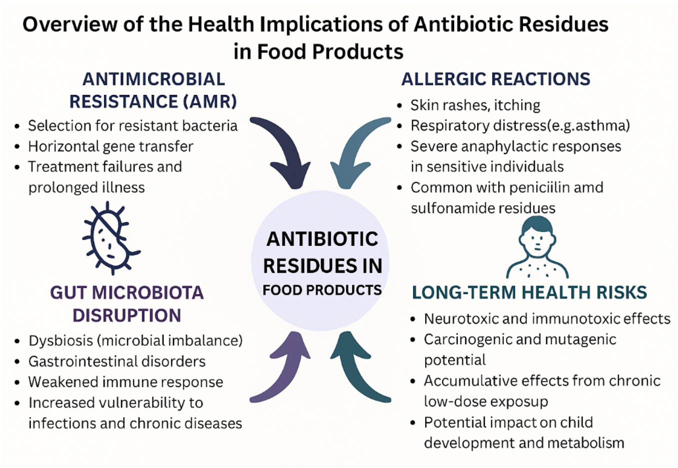

Figure 1: Outlines of the health risk assessment of antibiotic resistance in poultry products.

Residues can form at multiple stages of the poultry production process. During the active production phase, antibiotics are metabolized into various compounds some active, others inactive which may remain in tissues long after administration [7]. In the processing phase, activities such as slaughtering, handling, and packaging can either contribute to the persistence of residues or lead to cross-contamination if not managed correctly [63]. Post-processing, conservation conditions particularly temperature and duration also influence residue stability. Extended refrigeration or freezing may not substantially decompose and, in some cases, can even concentrate them further over time [49].

The impact of cooking on antibiotic residues is another critical factor for consumer safety. Many antibiotics, particularly heat-sensitive types like tetracyclines and sulfonamides, degrade when subjected to high temperatures through boiling, roasting, or grilling [53]. This thermal degradation alters their molecular structure, reducing their biological activity or converting them into less harmful derivatives. The degree to which residues are broken down be determined by on multifactorial involving the specific antibiotic, preparation technique, temperature, and exposure time [49,70]. Despite the benefits of cooking in reducing residue levels, it is not always fully effective especially when the initial contamination levels are high or when heat-stable antibiotics such as fluoroquinolones are involved [2].

Health problems of antibiotic residues and resistance

The presence of antibiotic residues and other contaminants in food and the system poses a complex and escalating public health challenge [93]. These residues remnants of pharmaceuticals commonly used in animal agriculture can have profound effects on human health. Chief among these are the promotion of AMR, the potential to trigger allergic responses, and the disruption of the human gut microbiome [39,78,99]. When such residues persist in food products, including meat, milk, and eggs, they present a direct threat to consumers, warranting critical attention and intervention [26]. Figure 1 provides a visual overview of the various health risks associated with the consumption of antibiotic-contaminated food products.

Antimicrobial resistance is a major global health concern, primarily fueled by the excessive and improper use of antibiotics in both human healthcare and animal agriculture [4,64]. Continuous exposure of microbial populations to subtherapeutic levels of antibiotics often through residues in food encourages the evolution of resistant bacterial strains [24]. This growing resistance undermines the effectiveness of current antibiotics, resulting in more severe infections, higher treatment failure rates, and increased morbidity and mortality [10]. The World Health Organization (WHO) recognizes AMR as one of the top ten threats to global health, urging immediate and coordinated intervention.

Beyond resistance, antibiotic residues pose direct health risks to consumers. These include allergic reactions ranging from mild irritations to life-threatening anaphylaxis especially in individuals sensitive to common antibiotics like penicillin [12]. Another significant concern is the disruption of the gut microbiota, or dysbiosis, which can weaken immune function and contribute to gastrointestinal and systemic diseases [45].

Real-world examples further illustrate the health crisis of antimicrobial drug residues. In India, researchers identified antibiotic-resistant *Escherichia coli* in river water contaminated with antibiotic residues, underscoring the potential for environmental exposure to contribute to AMR [83]. Correspondingly, research in Pakistan detected residues in beef products, upbringing alarms about human exposure through contaminated food sources [24].

Chronic, low-level exposure to antibiotic residues often through daily dietary intake may also lead to cumulative health consequences. Studies suggest links to carcinogenic effects, neurotoxicity, and immune suppression, even in the absence of acute symptoms [3,12]. This highlights the importance of monitoring long-term exposure to these contaminants in the food supply.

The environmental dimension of antibiotic residues compounds the problem. Antibiotics excreted in animal waste or discharged into water bodies through hospital and agricultural runoff persist in ecosystems, selecting for resistant bacteria and facilitating horizontal gene transfer of resistance genes [9,12,71,73]. Environmental reservoirs of resistance formed in soil, sediment, and wastewater can serve as breeding grounds for multidrug-resistant pathogens that eventually make their way into human and animal populations [34]. Key contributing factors include inadequate waste management, insufficient sewage treatment, and the unregulated utilization of antibiotics in farming, cultivation, husbandry and aquafarming [14].

In essence, the health entanglement of antibiotic residues extends from individual-level risks such as allergic responses and dysbiosis, to population-level threats like AMR and environmental contamination. Addressing this issue requires a holistic approach that encompasses food safety regulation, environmental protection, and sustainable antimicrobial use.

Public health issues and antibiotic resistance

AMR has become one of the most pressing public health crises of our time. Recognizing its severity, the World Health Organization (WHO) has identified AMR as one of the foremost global health threats of the 21st century. In 2019 alone, an estimated 1.27 million deaths were directly caused by antibiotic-resistant infections, with an additional 4.95 million deaths associated with illnesses involving resistant pathogens. These staggering figures highlight the critical urgency of implementing robust and coordinated strategies to address AMR on a global scale.

AMR is a complex and evolving issue, influenced by a range of interrelated factors including the persistence of antibiotic residues in food and the environment, inappropriate agricultural practices, and inadequate infection control measures within healthcare systems [73]. Addressing this multifaceted challenge requires an integrated approach that spans public health, veterinary medicine, agriculture, and environmental management. Table 2 outlines the major social health of antibiotic residues and their contribution to the development and spread of AMR.

Table 2: Public health considerations of antibiotic residues and their role in AMR.

Category	Key Aspects	Public Health Implications
Contribution to AMR development	- Exposure to low-dose antibiotic residues - Selection pressure on bacterial populations	- Accelerates the emergence of resistant strains - Reduces the efficacy of existing antibiotics
Environmental reservoirs of resistance	- Residues in soil, water, and food samples. - Horizontal gene transfer in microbial communities	- Facilitates the spread of resistance genes - Increases environmental and food chain transmission risks
Transmission from animals to humans	- Consumption of polluted poultry products - Direct contact with animals - Cross-contamination	- Heightened risk of difficult-to-treat infections - Increased potential for community outbreaks
Healthcare and treatment challenges	- Resistant infections require stronger or alternative drugs - Complications in surgical or medical care	- Increased treatment costs - Prolonged hospital stays and higher morbidity/mortality rates
Global burden and systemic impact	- Disruption of public health infrastructure - Rising demand on healthcare systems	- Estimated economic losses in trillions if unaddressed - Threat to food safety, security, and human health

The contribution of antimicrobial residues to the progress of AMR is a growing concern in both scientific and public health communities. These residues can continue in the surroundings particularly in water bodies, soil, and food products creating selective pressure that fosters the survival and proliferation of resistant bacteria. This environmental persistence not only supports the evolution of resistance but also facilitates horizontal gene transfer between microbial populations, thereby accelerating the dissemination of resistance traits [82,90].

Such environmental pollution is continually driven by husbandry techniques where antibiotics are applied not only for treating illnesses but also as feed efficiency enhancers in animal production [44]. The routine and sometimes assorted application of antibiotics in animal husbandry plays a significant role in the emergence of resistant bacterial strains. Resistance mechanisms frequently arise through gene transfer among bacteria, enabling the spread of resistance from animals to humans [14,73]. For example, Campylobacter species, commonly found in poultry, have exhibited increasing resistance to multiple antibiotics, posing a major risk to public health due to their relationship with foodborne disease [36,66].

The One Health approach recognizing the interconnectedness of human, animal, and environmental health has become

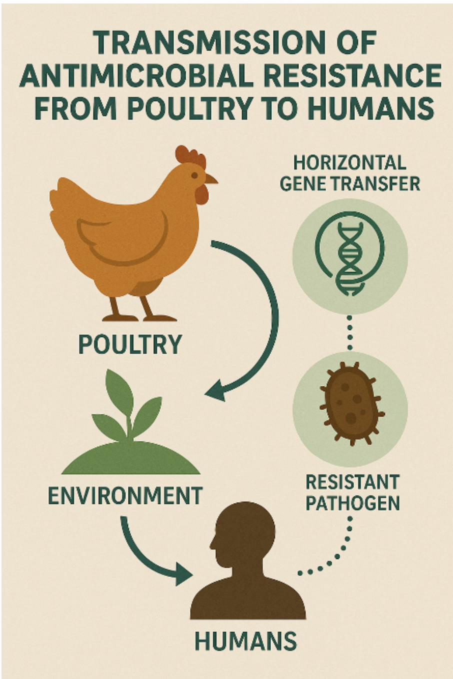

Figure 2: Transmission of AMR from poultry to humans.

essential in addressing the AMR crisis. This integrated strategy calls for cross-sectoral collaboration to effectively reduce antibiotic misuse and control the spread of resistant organisms across ecosystems.

One of the primary routes through which AMR spreads to humans is via the transmission of resistant bacteria from livestock, particularly poultry (Figure 2). This can occur through the consumption of contaminated food, direct animal contact, or exposure to contaminated environments [33,81]. For instance, Methicillin-Resistant Staphylococcus Aureus (MRSA) has been detected in poultry populations and is capable of causing severe and difficult-to-treat infections in humans [5]. These complex transmission dynamics highlight the necessity for interdisciplinary efforts involving public health, veterinary medicine, and environmental management to contain AMR [68].

Globally, the burden of AMR on healthcare systems is already substantial and continues to grow. Infections caused by resistant pathogens often lead to prolonged illness, increased hospitalizations, higher treatment costs, and greater rates of treatment failure [15]. The economic impact is staggering; if left unchecked, AMR could result in cumulative global losses exceeding $100 trillion by 2050. Hospital-Acquired Infections (HAIs), many of which involve resistant bacteria, contribute significantly to this economic and public health burden due to extended hospital stays and the need for more intensive treatments [21].

To combat AMR effectively, a multifaceted strategy is essential. This includes enhancing preventative and control measures, promoting the prudent use of antibiotics through optimized prescribing practices, and fostering widespread common knowledge concerning the consequences of antibiotic misuse [4,65].

Public education and community engagement play a central role in this effort. Many individuals remain unknowing of how drug resistance develops and how it affects health problems [64]. Targeted awareness programs that clearly communicate the exposure of unnecessary antibiotic use have been shown to influence behaviour positively [28]. Tailored messaging especially when distributed through trusted social networks can be particularly effective in communities where skepticism toward health authorities may exist. Collaborative efforts between health officials and community leaders are crucial to ensuring that educational messages are well-received and culturally appropriate.

Empowering individuals through knowledge can inspire more responsible behavior, helping to establish a societal culture of antibiotic stewardship [23]. This collective action is vital for preserving antibiotic efficacy and protecting global health systems from collapse under the weight of widespread resistance.

Additionally, maintaining antimicrobial effectiveness across all domain's human, animal, and plant health is essential for sustainable development [73]. Natural products, including plant-derived compounds and bioactive agents, have shown promising antimicrobial activity and may offer viable alternatives to synthetic antibiotics (Li et al., 2024) [67]. Nonetheless, the seriousness of the AMR threat demands urgent attention and action at every level.

A key component of the solution is the implementation of antimicrobial stewardship programs. These initiatives aim to ensure that antibiotics are used appropriately and only when truly necessary, thereby reducing selective pressure on bacteria. Effective stewardship not only improves individual patient outcomes by tailoring therapy to specific infections but also limits the emergence of resistance [90]. Furthermore, continuous surveillance of resistance trends is essential to inform treatment guidelines and public health policy [17].

Ultimately, integrating antimicrobial stewardship with sustainable agricultural practices will be vital in reducing environmental exposure to antibiotic residues. This holistic, One Health-aligned approach represents the most promising path forward in addressing the escalating threat of AMR.

Legislative frameworks and policy

Robust regulatory frameworks and clearly defined guidelines governing the use of antibiotics in food production are essential to safeguarding public health and ensuring the safety of food products. The presence of antibiotic residues in meat, eggs, and other consumables can result in serious health consequences, involving hypersensitivity and the promotion of AMR both of which represent notable public health threats.

To mitigate these risks, a range of international and national regulatory bodies have established MRLs the highest levels of drug residues legally permitted in food products. These limits serve as critical benchmarks for food safety enforcement and consumer protection.

One of the most influential global initiatives in this regard is the Codex Alimentarius, jointly developed by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The Codex provides standardized guidelines and MRLs for various veterinary drugs, including antibiotics, to support international trade and harmonize food safety practices across nations. These standards help ensure that food products circulating in global markets meet minimum safety requirements and do not pose a health risk to consumers [87]. Figure 3 illustrates a conceptual structure for controlling antibiotic residues within the food processing chain, encompassing monitoring, regulation, and enforcement components.

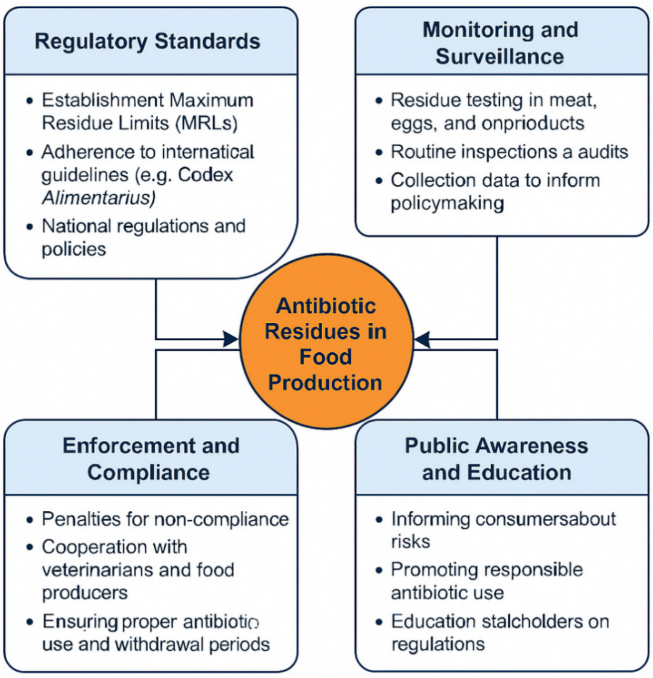

Figure 3: Structural for controlling antibiotic residues in food production.

Alongside global frameworks, many individual states have established their own restriction to manage drug residues in food products. For example, the European Union (EU) has implemented some of the world's most stringent measures, forbidding the utilization of specific antibiotics as growth stimulants in livestock and enforcing strict MRLs for antibiotics in food [1,59]. Similarly, in the United States, the Animal Drug Availability Act control the application of antibiotics in food-producing animals and mandates withdrawal periods to guaranty that residues remain below substantiated safety thresholds before animals are slaughtered [36]. These frameworks are essential for preserving users from the health hazards related with antimicrobial residues.

Surveillance and regulation are central to the success of these regulatory systems. Effective surveillance programs ensure compliance with MRLs and enable the prompt detection and correction of violations. Denmark's "Yellow Card Initiative" is a notable example; by conducting semi-annual audits of animal healthcare and maintaining a national database tracking antibiotic prescription, the program has significantly reduced antibiotic adoption in animal husbandry. Similarly, Vietnam has introduced residue monitoring programs for aquaculture products to ensure compliance with food safety standards before distribution [72]. These initiatives demonstrate that active monitoring is crucial for safeguarding food sanitation and community health.

In addition to regulatory oversight, health and farming organizations have launched diverse initiatives to promote responsible antibiotic application. The World Organization for Animal Health (OIE) and the Food and Agriculture Organization (FAO) have developed programs aimed at minimizing antibiotic reliance in livestock farming [62,83,99]. These initiatives advocate for reinforced livestock farming, enhanced disease prevention strategies, and the use of non-antibiotic alternatives such as probiotics and phytogenic feed additives. Adoption of these practices helps maintain animal health while reducing the risk of antibiotic resistance, supporting a more sustainable approach to food production [42,51].

The impact of antibiotic use extends beyond food safety into environmental health. Residual antibiotics able to pollute soil and water distribution systems, promoting the emergence and spread of ARB in the atmosphere (Kaur et al., 2024). Research has displayed that the employment of manure enclosing antibiotic residues can select for resistant genes in cultivated lands, threatening harm to ecological health stability [84,100]. Therefore, comprehensive regulatory frameworks must also consider environmental protection measures to effectively address the broader consequences of antibiotic use in agriculture.

Beyond regulations, public education and awareness play a vital role in reducing antibiotic misuse. Training farmers and veterinarians on the dangers of unsuitable antibiotic use and the significance of compliance with regulations is essential. In the United Kingdom, public service programs targeted at livestock farmers have successfully reduced antibiotic usage rates [16]. These initiatives are instrumental in cultivating a practice of prudent antimicrobial utilization within the animal agricultural industry.

The financial impacts of antibiotic regulation are also important to consider. Compliance with MRLs and the adoption of different management implementations may initially impose higher costs on farmers. However, long-term benefits for instance enhanced animal health, better production efficiency, and lower medical expenditure affiliated with treating resistant infections can ultimately exceed these expenses [4]. Policymakers must, therefore, balance the short-term economic challenges with the broader public health and environmental benefits when designing regulatory measures.

Given the globalized nature of food processing and trade, global collaboration is indispensable. The Codex Alimentarius serves as a vital platform for harmonizing food hygiene regulations worldwide, involving those governing antimicrobial drug residues [79]. Additionally, institutions like the WHO and FAO are instrumental in encouraging sustainable antimicrobial uses in husbandry through cooperative ventures [4]. Their work aims to mitigate the threats posed by antibiotic resistance and ensure the long-term effectiveness of these critical medications [90]. Such coordinated exertions are imperative for protecting global safe food handling, public safety and security, and the capability of antibiotics for next generations.

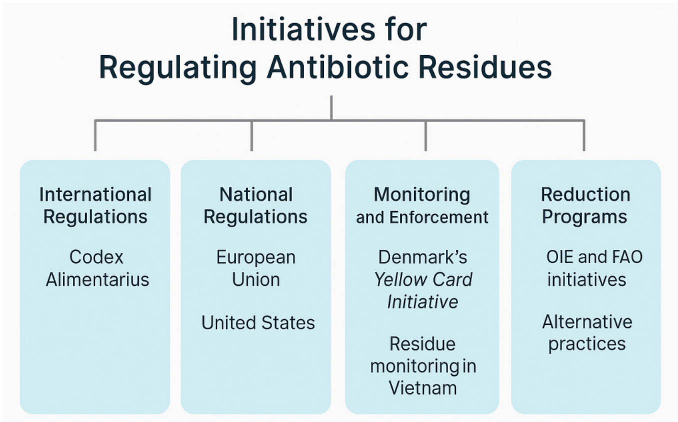

Figure 4: Key international and national initiatives for regulating antibiotic residues in food production.

Monitoring, control, analysis, and mitigation of antibiotic residues

The mitigation, monitoring, and administration plan of antibiotic traces in livestock farming are essential components of food security and sanitary measures protection. Leftovers can arise from both the prophylactic and therapeutic use of antibiotics in poultry production, posing significant health threats to users if not properly controlled.

To address this issue, a variety of detection techniques have been developed, encompassing both chemical and microbiological methods. These tools are crucial for verifying the safety of poultry products before they reach the market. Among the widely used approaches, microbiological inhibition tests stand out for preliminary screening purposes. These tests are valued for their simplicity, cost-effectiveness, and ability to process large numbers of samples simultaneously [19,92]. By detecting the presence of antibiotic residues in poultry tissues, such methods play a pivotal role in reducing consumer exposure and mitigating associated health risks. Table 3 provides an outline of key approach for handling antibiotic residues effectively within poultry breeding operations.

Table 3: Strategies for the detection and management of antibiotic residues in poultry farming.

Strategy Category	Description	Purpose/Outcome
Monitoring and surveillance	Regular sampling and testing of poultry tissues, eggs, and feed using validated methods.	Detects residues early, ensures compliance with MRLs, and maintains food safety standards.
Screening tests (Microbiological)	Use of microbiological inhibition assays (Bacillus subtilis or Geobacillus stearothermophilus based tests).	Cost-effective, rapid detection of broad-spectrum antibiotic activity in samples.
Confirmatory analytical methods	Advanced techniques such as HPLC, LC-MS/MS, and GC-MS for residue quantification and identification.	Provides precise, quantitative data for regulatory compliance and enforcement.
Withdrawal period enforcement	Mandated time between last antibiotic administration and slaughter/egg collection.	Allows drug clearance from the animal's system, preventing violative residue levels.
Veterinary oversight	Prescribing and administering antibiotics under licensed veterinary supervision.	Reduces inappropriate or off-label antibiotic use.
Education and training	Informing farmers and handlers about responsible antibiotic use and residue risks.	Promotes compliance with safety guidelines and reduces misuse.
Alternative practices	Use of probiotics, prebiotics, phytogenics, and improved husbandry instead of antibiotics.	Decreases the need for antibiotics, minimizing the risk of residue accumulation.
Traceability systems	Implementation of record-keeping and digital tracking of drug use across production stages.	Enhances accountability and allows for targeted interventions in case of violations.

Beyond microbiological assays, a range of chemical detection methods including enzyme-linked immunosorbent assays (ELISA) and chromatographic techniques (separation process) are widely employed for the exact amount of antibiotic residues in production of poultry [36]. These advanced methods offer superior specificity and sensitivity contrasted to conventional microbiological tests, enabling the exploration of even trace concentrations of antibiotic compounds. For instance, research have demonstrated the effectiveness of ELISA in identifying residues of antibiotics such as macrolides and tetracyclines in poultry tissues with high accuracy [61]. The integration of both microbiological and chemical detection approaches is crucial for comprehensive monitoring efforts, ensuring adherence to the MRLs established by regulatory authorities [13].

Preventing accumulation of antibiotic residues in domestic bird products hinges on the adoption of best practices at the farm level. Central to these practices is strict adherence to withdrawal periods the prescribed interval between the final antibiotic treatment and the slaughter or collection of animal products [2,6]. Ignoring these withdrawal times can result in violative residue levels in meat and eggs, posing significant risks to consumer health [88]. Furthermore, promoting farmer education and raising awareness about responsible antibiotic use and the importance of veterinary oversight are vital steps in curbing indiscriminate antibiotic administration, which is often linked to gaps in knowledge and limited entry to veterinary care. Executing rigorous record-keeping and monitoring systems also helps farmers supervise drug utilization and maintain compliance with food safety qualities.

The move toward substitutes to antibiotics in broiler production is gaining momentum as a sustainable solution for reducing dependency on antimicrobial drugs. Probiotics, for example, have been shown to enhance gut health, boost the immune response, and lower the incidence of disease in broiler, thereby diminishing the require for antimicrobial interventions [22,69,97]. Similarly, vaccination programs effectively prevent infections that would otherwise require antibiotic treatment, further supporting the reduction of antibiotic use in poultry production [52]. The incorporation of these alternatives promotes not only animal husbandry welfare but also environmental sustainability by minimizing the ecological impacts associated with antibiotic usage.

In addition to probiotics and vaccines, prebiotics and phytogenics natural bioactive compounds derived from plants have emerged as promising tools to improve poultry health and production efficiency without resorting to antibiotics. These substances can enhance gut microbiota balance, improve nutritional uptake, and promote exceptional growth rates and feed efficacy. Investigation has shown that the use of such alternatives positively reduces infection rates among poultry flocks, thereby decreasing reliance on antibiotic treatments [81,97]. This shift towards non-antibiotic strategies is consistent with global initiatives aimed at combating antimicrobial resistance and promoting responsible antibiotic stewardship in husbandry.

The public health risks associated with antibiotic residues in poultry products remain profound. Consumption of contaminated products can lead to a range of adverse effects, comprising hypersensitivity and the emergence of ARB [54]. Recognizing the severity of this threat, the World Health Organization (WHO) has identified antibiotic resistance as a major global health crisis, underscoring the need for effective monitoring and stringent management strategies [54]. Strengthening regulatory frameworks and ensuring strict enforcement of safety standards are critical to protecting consumers and maintaining public confidence in food systems.

Mitigating the impact of antibiotic residues through one health approaches and the exploration of sustainable alternatives

The impact of antibiotic residues on one health

The existence of antimicrobial residues in agricultural commodities derived from animals presents significant risks to public health, animal health, and the environment [32]. These residues can exert direct detrimental effects on users, contributing to serious health conditions [140,142]. Beyond direct toxicity, the transmission of ARB and Antibiotic Resistance Genes (ARGs) from animals to humans' transmission through the food cycle remains a critical issue [59,86].

Epidemiological studies have further revealed that early-life experience to antibiotics whether across the food supplies or clean drinking water is associated with a greater chance of harm of pediatric obesity [95]. Disruption of the gut microbiota due to antibiotic residues has also been implicated in the development of metabolic disorders and other long-term health consequences [98]. In the dairy sector, antibiotic residues present an additional challenge by inhibiting the growth of starter cultures utilized in fermentation, leading to substantial financial losses for dairy producers [80,91].

The widespread application of antibiotics in livestock production has undeniably fueled the emergence and spread of antibiotic resistance, posing a serious threat to global health [48,86]. Addressing this complex issue demands the adoption of a One Health approach, which acknowledges the intricate connections between human, animal, and environmental health. To mitigate these risks, comprehensive and integrated strategies are essential, including the robust management and controlling of antibiotic residues, promoting sustainable farming practices, and ensuring the prudent use of antibiotics. Such measures are vital not only to guarantee food safety and control infectious diseases but also to preserve the effectiveness of life-saving antibiotics for future generations [59,90].

Table 4: Cross-sector impacts of antibiotic residues on one health domains.

Domain	Impact	Example
Human health	AMR, metabolic disorders.	Obesity risk from early-life exposure.
Animal health	Altered gut flora.	Reduced immunity in poultry.
Environment	ARGs in water/soil.	River contamination from manure runoff

Sustainable alternatives to antibiotics for promoting fresh agricultural production

To counteract the detrimental impacts of antibiotic residues and the escalating hazard of antibiotic resistance, scientist have increasingly focused on identifying sustainable alternatives to antibiotics for employ in agricultural supply systems (Figure 5). Beyond technologies such as photocatalytic methods, one particularly promising solution is the application of biochar a carbon-rich material produced through the pyrolysis of organic matter [37]. Latest findings have demonstrated that biochar can productively reduce or eliminate antibiotic residues, ARGs, and additional pollutants from soil and water environments [25,76].

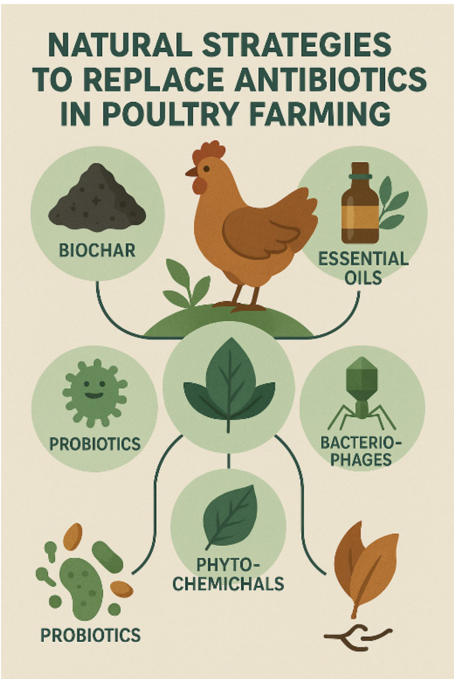

Figure 5: Natural strategies to replace antibiotics in poultry farming.

Integrating biochar into the food supply chain offers a valuable strategy for mitigating the spread of antibiotic residues and resistant bacteria, thereby enhancing food safety and protecting public health [25]. Moreover, the application of biochar aligns with the fundamental of sustainable economic and green development, as it accommodates an environmentally friendly and economically viable result for contamination control [74,75].

In addition to biochar, several other natural alternatives are being analyzed as substitutions for traditional antibiotics in livestock farming and crop production. These include essential oils, various plant-derived bioactive compounds [93,97], and bacteriophages viruses that specifically target and destroy bacterial pathogens [27]. Such natural compounds have demonstrated considerable potential in prohibiting the development of harmful bacteria without promoting the antibiotic resistance growth.

Assimilating a holistic route that integrates rigorous measurement and control of antibiotic residues, while simultaneously implementing natural alternatives, represents a critical step toward security, protection, quality, and continuity of the global food supply. Through collaborative efforts between industry stakeholders, researchers, and regulatory agencies, it is possible to address the dual challenges of food safety and antibiotic resistance, preserving both public health and the effectiveness of antimicrobial agents for future generations [90].

Risk mitigation strategies and prevention measures

Addressing the health hazards interrelated with antibiotic employment in broiler production is increasingly urgent, particularly given the global rise of AMR. Implementing targeted and impressive policy measures is imperative to mitigate these exposures. One key strategy is the strengthening of regulations governing antibiotic use in chicken production through the development of stricter regulations and enhanced surveillance systems. Research shows that widespread, indiscriminate antibiotic use often stems from limited animal healthcare and self- treatment among agriculturist [4,50]. By establishing specialized management structures to control antibiotic entry and consumption, legislators can remarkably diminish the presence of antibiotic residues in animal husbandry [1].

Educational initiatives are equally critical in reshaping farmers' approaches toward antibiotic application. Evidence suggests that advancing farmer knowledge on biosecurity practices and poultry health administration can lead to reduced antibiotic dependency [11,50]. Educational programs should be integrated with the promotion of outstanding management methods across the poultry production chain, encouraging more responsible antibiotic usage [77]. Furthermore, ensuring that veterinarians are actively involved in prescribing and advising on antibiotic use can guide farmers toward more judicious and scientifically informed decisions [31,89].

Promoting organic farming implementations is another essential guidance to reduce health problems [29,43]. Sustainable agriculture minimizes antibiotic dependence by fostering overall farm resilience and animal health. Natural alternatives incorporating probiotics and phytochemicals have obtained recognition as productive approaches to improve poultry disease management while minimizing the environmental burden of antibiotic employment [38,96]. Adopting these alternatives supports both farm productivity and environmental sustainability by lowering the risks associated with antimicrobial contamination [29]. Moreover, sustainable farming often incorporates strengthened disease prevention protocols, which are vital for avoiding the disseminate of infectious diseases [35,40].

Financial incentives and targeted educational programs can further accelerate the adoption of sustainable practices. Governments should consider providing subsidies, tax incentives, or financial support to farmers who applied environmentally conscious and antibiotic-reducing implementation [85]. Additionally, agricultural extension services should focus on promoting the long-term economic and health benefits of sustainable farming methods through tailored outreach and training initiatives [58].

Enhancing food safety management systems is pivotal for assuring that poultry products entering the food supply are free from harmful antibiotic residues [81]. Robust residue testing protocols, integrated into public health surveillance networks, are essential for detecting contaminated products early and preventing their distribution [41]. Incorporating food safety management with broader health services initiatives provides an extensive framework for handling AMR risks effectively [4,36].

The conservation dimension of antibiotic use must also be addressed. Studies reveal that ARB can persist in agricultural environments, especially where antibiotics are heavily utilized [9,81]. Executing environmental impact analysis for instance advanced wastewater treatment, proper manure removal, and soil contamination prevention can help minimize the spread of resistant bacteria and protect both public health and ecosystem integrity.

Finally, collaborative, multi-sectoral action is fundamental to the promising execution of these suggestions. Active partnerships between farmers, veterinarians, policymakers, public health professionals, and research institutions can facilitate the exchange of understanding and resources, heading to more innovative and practical solutions for lowering antibiotic use in broiler production. A One Health approach, recognizing the interconnectedness of human, animal, and environmental health, should underpin all efforts to combat AMR and safeguard global food systems.

Conclusion and perspectives

The existence of antibiotic residues in domesticated broiler products represents a substantial threat to community health, contributing to allergic toxicity, and, very seriously, the development of AMR. The widespread misapplication and overuse of antibiotics in animal husbandry have accelerated the development of resistant bacterial strains, that may be disseminated to humans via the consumption of unclean meat. AMR poses a formidable international health issues, undermining the efficacy of essential antibiotics needed to treat infections. Moreover, chronic disclosure to low levels of antimicrobial residues allow interrupt the gut microbiota, increasing the risk of metabolic disorders, immune dysfunction, and other long-term health issues.

Addressing these public health risks demands a multifaceted approach, including the implementation of rigorous regulations to control antibiotic utilization, the promotion of advanced farming techniques, and the encouragement of natural alternatives like probiotic supplementation, vaccine, phytogenic additives. In addition, outreach programs are vital to educate users on the dangers interrelated with antimicrobial residues and to promote the adoption of ecological, responsible farming systems.

To effectively reduce the contact of antibiotic residues on human health, an extensive and supportive strategy is essential. This comprises executing robust regulatory frameworks, advancing the adoption of antimicrobial peptides in chicken production, and expanding educational efforts to inform consumers and stakeholders about food safety risks. Future research should focus on developing highly sensitive and rapid detection methods for antibiotic residues, investigating safer and more effective disease control strategies in husbandry, and deepening our comprehending of the health impacts associated with prolonged, low-level antibiotic exposure.

Through synergetic action among legislative agencies, the scientific community, agricultural producers, and public health advocates, it is possible to significantly reduce the risks associated with antibiotic residues, protect food safety, and preserve the effectiveness of antibiotics for future generations.

Author declarations

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References

1. Abou-Jaoudeh C, Andary J, Abou-Khalil R. Antibiotic residues in poultry products and bacterial resistance: A review in developing countries. J Infect Public Health. 2024; 17: 102592.
2. Adegbeye MJ, Adetuyi BO, Igirigi AI, Adisa A, Palangi V, Aiyedun S, Alvarado-Ramírez ER, Elghandour MMMY, Molina OM, Oladipo AA, Salem AZM. Comprehensive insights into antibiotic residues in livestock products: Distribution, factors, challenges, opportunities, and implications for food safety and public health. Food Control. 2024; 163: 110545.
3. Ahmad MF, Ahmad FA, Alsayegh AA, Zeyaullah M, AlShahrani AM, Muzammil K, Saati AA, Wahab S, Elbendary EY, Kambal N, Abdelrahman MH, Hussain S. Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. Heliyon. 2024; 10: e29128.
4. Ahmed SK, Hussein S, Qurbani K, Ibrahim RH, Fareeq A, Mahmood KA, Mohamed MG. Antimicrobial resistance: Impacts, challenges, and future prospects. J Med Surg Public Health. 2024; 2: 100081.
5. Aires-de-Sousa M. Methicillin-resistant Staphylococcus aureus among animals: current overview. Clin Microbiol Infect. 2017; 23: 373-80.
6. Alban L, Antunovic B, Belous M, Bērziņš A, Bonardi S, García-Gimeno RM, Jenson I, Kautto AH, Majewski M, Oorburg D, Sakaridis I, Sirbu A, Vieira-Pinto M, Vågsholm I, Petersen JV. Accidental delivery of pigs for slaughter prior to end of withdrawal period for antimicrobial treatment - Ways of handling. Food Control. 2023; 154: 110000.
7. Alves EC, dos Santos Alves IH, Soares BB, Borges AF, Jalal A, Jani AD, Abreu-Junior CH, Capra GF, Rodrigues Nogueira TA. Resource recovery of biological residues from the Brazilian poultry industry in mitigating environmental impacts: A life cycle assessment approach. J Clean Prod. 2023; 416: 137895.
8. Baéza E, Guillier L, Petracci M. Production factors affecting poultry carcass and meat quality attributes. Animal. 2022; 16: 100331.

9. Barathe P, Kaur K, Reddy S, Shriram V, Kumar V. Antibiotic pollution and associated antimicrobial resistance in the environment. J Hazard Mater Lett. 2024; 5: 100105.

10. Bashir N, Dablool AS, Khan MI, Almalki MG, Ahmed A, Mir MA, Hamdoon AAE, Elawad MA, Mosa OF, Niyazov LN, Elkhalifa MEM, Alghamdi MA, Anwar A, Ayaz M. Antibiotics resistance as a major public health concern: A pharmaco-epidemiological study to evaluate prevalence and antibiotics susceptibility-resistance pattern of bacterial isolates from multiple teaching hospitals. J Infect Public Health. 2023; 16: 61-8.

11. Bâtie C, Ha LTT, Loire E, Truong DB, Tuan HM, Cuc NTK, Paul M, Goutard F. Characterisation of chicken farms in Vietnam: A typology of antimicrobial use among different production systems. Prev Vet Med. 2022; 208: 105731.

12. Ben Y, Fu C, Hu M, Liu L, Wong MH, Zheng C. Human health risk assessment of antibiotic resistance associated with antibiotic residues in the environment: A review. Environ Res. 2019; 169: 483-93.

13. Bist RB, Bist K, Poudel S, Subedi D, Yang X, Paneru B, Mani S, Wang D, Chai L. Sustainable poultry farming practices: a critical review of current strategies and future prospects. Poult Sci. 2024; 103: 104295.

14. Bobate S, Mahalle S, Dafale NA, Bajaj A. Emergence of environmental antibiotic resistance: Mechanism, monitoring and management. Environ Adv. 2023; 13: 100409.

15. Bonna AS, Pavel SR, Ferdous J, Khan SA, Ali M. Antibiotic resistance: An increasingly threatening but neglected public health challenge in Bangladesh. Int J Surg Open. 2022; 49: 100581.

16. Borelli E, Ellis K, Pamphilis NM, Tomlinson M, Hotchkiss E. Factors influencing Scottish dairy farmers' antimicrobial usage, knowledge and attitude towards antimicrobial resistance. Prev Vet Med. 2023; 221: 106073.

17. Cantón R, Gottlieb T, Coombs GW, Woo PCY, Korman TM, Garcia-Castillo M, Daley D, Bauer KA, Wong M, Wolf DJ, Siddiqui F, Motyl M. Antimicrobial surveillance: A 20-year history of the SMART approach to addressing global antimicrobial resistance into the future. Int J Antimicrob Agents. 2023; 62: 107014.

18. Castro FLS, Chai L, Arango J, Owens CM, Smith PA, Reichelt S, DuBois C, Menconi A. Poultry industry paradigms: connecting the dots. J Appl Poult Res. 2023; 32: 100310.

19. Chen J, Zhang J, Wang N, Xiao B, Sun X, Li J, Zhong K, Yang L, Pang X, Huang F, Chen A. Critical review and recent advances of emerging real-time and non-destructive strategies for meat spoilage monitoring. Food Chem. 2024; 445: 138755.

20. Chen Y, Liu Y, Zhao C, Ma J, Guo J. Antibiotic resistance gene pollution in poultry farming environments and approaches for mitigation: A system review. Poult Sci. 2025; 104: 104858.

21. Despotovic A, Milosevic B, Milosevic I, Mitrovic N, Cirkovic A, Jovanovic S, Stevanovic G. Hospital-acquired infections in the adult intensive care unit: Epidemiology, antimicrobial resistance patterns, and risk factors for acquisition and mortality. Am J Infect Control. 2020; 48: 1211-5.

22. Dibakoane SR, Mhlongo G, Moonsamy G, Wokadala OC, Mnisi CM, Mlambo V. Phenomenological and mechanistic insights into potential dietary nucleotide–probiotic synergies in layer chickens: A review. Poult Sci. 2025; 104: 105049.

23. Ding D, Wang B, Zhang X, Zhang J, Zhang H, Liu X, Gao Z, Yu Z. The spread of antibiotic resistance to humans and potential protection strategies. Ecotoxicol Environ Saf. 2023; 254: 114734.

24. Duan K, Pang G, Duan Y, Onyeaka H, Krebs J. Current research development on food contaminants, future risks, regulatory regime and detection technologies: A systematic literature review. J Environ Manage. 2025; 381: 125246.

25. Ejileugha C. Biochar can mitigate co-selection and control antibiotic resistant genes in compost and soil. Heliyon. 2022; 8: e09543.

26. Farber JM, Zwietering M, Wiedmann M, Schaffner D, Hedberg CW, Harrison MA, Hartnett E, Chapman B, Donnelly CW, Goodburn KE, Gummalla S. Alternative approaches to the risk management of Listeria monocytogenes in low risk foods. Food Control. 2021; 123: 107601.

27. Faruk O, Jewel ZA, Bairagi S, Rasheduzzaman M, Bagchi H, Tuha ASM, Hossain I, Bala A, Ali S. Phage treatment of multidrug-resistant bacterial infections in humans, animals, and plants: The current status and future prospects. Infect Med. 2025; 4: 100168.

28. Fatokun O, Magunga BT, Oranye N, Selvaraja M. Public awareness, risk perceptions and behaviour towards antibiotic use in food-producing animals and antimicrobial resistance in Malaysia: A cross-sectional study. Prev Vet Med. 2024; 228: 106224.

29. Gamage A, Gangahagedara R, Gamage J, Jayasinghe N, Kodikara N, Suraweera P, Merah O. Role of organic farming for achieving sustainability in agriculture. Farming Syst. 2023; 1: 100005.

30. Gentile A, Di Stasio L, Oliva G, Vigliotta G, Cicatelli A, Guarino F, Nissim WG, Labra M, Castiglione S. Antibiotic resistance in urban soils: Dynamics and mitigation strategies. Environ Res. 2024; 263: 120120.

31. Guenin MJ, Studnitz M, Molia S. Interventions to change antimicrobial use in livestock: A scoping review and an impact pathway analysis of what works, how, for whom and why. Prev Vet Med. 2023; 220: 106025.

32. Hassan MM, El Zowalaty ME, Lundkvist Å, Järhult JD, Khan Nayem MR, Tanzin AZ, Badsha MR, Khan SA, Ashour HM. Residual antimicrobial agents in food originating from animals. Trends Food Sci Technol. 2021; 111: 141-50.

33. Heredia N, García S. Animals as sources of food-borne pathogens: A review. Anim Nutr. 2018; 4: 250-5.

34. Hossein M, Ripanda AS. Pollution by antimicrobials and antibiotic resistance genes in East Africa: Occurrence, sources, and potential environmental implications. Toxicol Rep. 2025; 14: 101969.

35. Huber N, Andraud M, Sassu EL, Prigge C, Zoche-Golob V, Käsbohrer A, D'Angelantonio D, Viltrop A, Żmudzki J, Jones H, Smith RP, Tobias T, Burow E. What is a biosecurity measure? A definition proposal for animal production and linked processing operations. One Health. 2022; 15: 100433.

36. Izah SC, Nurmahanova A, Ogwu MC, Toktarbay Z, Umirbayeva Z, Ussen K, Koibasova L, Nazarbekova S, Tynybekov B, Guo Z. Public health risks associated with antibiotic residues in poultry food products. J Agric Food Res. 2025; 21: 101815.

37. Javanmard A, Bin Wan Daud WMA, Patah MFA, Zuki FM, Verdugo AS. Harnessing the potential of biochar-based catalysts for sustainable adsorptive and photocatalytic applications: A comprehensive review. Process Saf Environ Prot. 2024; 189: 387-413.

38. Jeni RE, Dittoe DK, Olson EG, Lourenco J, Corcionivoschi N, Ricke SC, Callaway TR. Probiotics and potential applications for alternative poultry production systems. Poult Sci. 2021; 100: 101156.

39. Jia Q, Liao G, Chen L, Qian Y, Yan X, Qiu J. Pesticide residues in animal-derived food: Current state and perspectives. Food Chem. 2024; 438: 137974.

40. Jimenez CEP, Keestra S, Tandon P, Cumming O, Pickering AJ, Moodley A, Chandler CIR. Biosecurity and water, sanitation, and hygiene interventions in animal agricultural settings for reducing infection burden, antibiotic use, and antibiotic resistance: A One Health systematic review. Lancet Planet Health. 2023; 7: e418-34.

41. Kadadou D, Tizani L, Alsafar H, Hasan SW. Analytical methods for determining environmental contaminants of concern in water and wastewater. MethodsX. 2024; 12: 102582.

42. Kaur K, Singh S, Kaur R. Impact of antibiotic usage in food-producing animals on food safety and possible antibiotic alternatives. Microbe. 2024; 4: 100097.

43. Kharel M, Dahal BM, Raut N. Good agriculture practices for safe food and sustainable agriculture in Nepal: A review. J Agric Food Res. 2022; 10: 100447.

44. Khmaissa M, Zouari-Mechichi H, Sciara G, Record E, Mechichi T. Pollution from livestock farming antibiotics: An emerging environmental and human health concern. J Hazard Mater Adv. 2024; 13: 100410.

45. Lathakumari RH, Vajravelu LK, Satheesan A, Ravi S, Thulukanam J. Antibiotics and the gut microbiome: Understanding the impact on human health. Med Microecol. 2024; 20: 100106.

46. Li S, Jiang S, Jia W, Guo T, Wang F, Li J, Yao Z. Natural antimicrobials from plants: Recent advances and future prospects. Food Chem. 2024; 432: 137231.

47. Lima É, Oliveira MB, Freitas A. Antibiotics in intensive egg production: Food safety tools to ensure regulatory compliance. Food Chem Adv. 2023; 3: 100548.

48. Ma F, Xu S, Tang Z, Li Z, Zhang L. Use of antimicrobials in food animals and impact of transmission of antimicrobial resistance on humans. Biosaf Health. 2021; 3: 32-8.

49. Mafe AN, Edo GI, Makia RS, Joshua OA, Akpoghelie PO, Gaaz TS, Jikah AN, Yousif E, Isoje EF, Igbuku UA, Ahmed DS, Essaghah AEA, Umar H. A review on food spoilage mechanisms, food borne diseases and commercial aspects of food preservation and processing. Food Chem Adv. 2024; 5: 100852.

50. Malijan GM, Howteerakul N, Ali N, Siri S, Kengganpanich M, Nascimento R, Booton RD, Turner KME, Cooper BS, Meeyai A. A scoping review of antibiotic use practices and drivers of inappropriate antibiotic use in animal farms in WHO Southeast Asia region. One Health. 2022; 15: 100412.

51. Mann A, Nehra K, Rana JS, Dahiya T. Antibiotic resistance in agriculture: Perspectives on upcoming strategies to overcome upsurge in resistance. Curr Res Microb Sci. 2021; 2: 100030.

52. Mehdi Y, Létourneau-Montminy MP, Gaucher ML, Chorfi Y, Suresh G, Rouissi T, Brar SK, Côté C, Ramirez AA, Godbout S. Use of antibiotics in broiler production: Global impacts and alternatives. Anim Nutr. 2018; 4: 170-8.

53. Merhi A, Khatib SE, Haddad J, Hassan HF. A review of the antibiotic residues in food in the Arab countries. Appl Food Res. 2023; 3: 100332.

54. Mithuna R, Tharanyalakshmi R, Jain I, Singhal S, Sikarwar D, Das S, Ranjitha J, Ghosh D, Rahman MM, Das B. Emergence of antibiotic resistance due to the excessive use of antibiotics in medicines and feed additives: A global scenario with emphasis on the Indian perspective. Emerg Contam. 2024; 10: 100389.

55. Mohammed AM, Mohammed M, Oleiwi JK, Osman AF, Adam T, Betar BO, Gopinath SCB, Ihmedee FH. Enhancing antimicrobial resistance strategies: Leveraging artificial intelligence for improved outcomes. S Afr J Chem Eng. 2025; 51: 272-86.

56. Muaz K, Riaz M, Akhtar S, Park S, Ismail A. Antibiotic residues in chicken meat: Global prevalence, threats, and decontamination strategies. J Food Prot. 2018; 81: 619-27.

57. Muloi DM, Kasudi MR, Murungi MK, Lusanji Ibayi E, Kahariri S, Karimi C, Korir M, Muasa B, Mwololo D, Ndanyi R, Ndungi R, Njiru J, Omani R, Owada R, Omulo S, Azegele A, Fèvre EM. Analysis of antibiotic use and access to drugs among poultry farmers in Kenya. One Health. 2025; 20: 100987.

58. Ofosu-Ampong K, Abera W, Müller A, Adjei-Nsiah S, Boateng R, Acheampong B. Framing behaviour change for sustainable agriculture: Themes, approaches, and future directions. Farming Syst. 2025; 3: 100123.

59. Okaiyeto SA, Sutar PP, Chen C, Ni JB, Wang J, Mujumdar AS, Zhang JS, Xu MQ, Fang XM, Zhang C, Xiao HW. Antibiotic resistant bacteria in food systems: Current status, resistance mechanisms, and mitigation strategies. Agric Commun. 2024; 2: 100027.

60. Onyeaka H, Akinsemolu A, Miri T, Nnaji ND, Duan K, Pang G, Tamasiga P, Khalid SZT, Ugwa C. Artificial intelligence in food system: Innovative approach to minimizing food spoilage and food waste. J Agric Food Res. 2025; 21: 101895.

61. Owusu-Doubreh B, Appaw WO, Abe-Inge V. Antibiotic residues in poultry eggs and its implications on public health: A review. Sci Afr. 2023; 19: e01456.

62. Patel SJ, Wellington M, Shah RM, Ferreira MJ. Antibiotic stewardship in food-producing animals: Challenges, progress, and opportunities. Clin Ther. 2020; 42: 1649–1658.

63. Podolak R, Enache E, Stone W, Black DG, Elliott PH. Sources and risk factors for contamination, survival, persistence, and heat resistance of Salmonella in low-moisture foods. J Food Prot. 2010; 73: 1919–1936.

64. Pulingam T, Parumasivam T, Gazzali AM, Sulaiman AM, Chee JY, Lakshmanan M, et al. Antimicrobial resistance: Prevalence, economic burden, mechanisms of resistance and strategies to overcome. Eur J Pharm Sci. 2022; 170: 106103.

65. Puri B, Vaishya R, Vaish A. Antimicrobial resistance: Current challenges and future directions. Med J Armed Forces India. 2024.

66. Rama EN, Bailey M, Kumar S, Leone C, den Bakker H, Thippareddi H, et al. Prevalence and antimicrobial resistance of Campylobacter in conventional and no antibiotics ever broiler farms. J Food Prot. 2024; 87: 100238.

67. Rasheed HA, Rehman A, Karim A, Al-Asmari F, Cui H, Lin L. A comprehensive insight into plant-derived extracts/bioactives: Exploring their antimicrobial mechanisms and potential for high-performance food applications. Food Biosci. 2024; 59: 104035.

68. Rees EM, Minter A, Edmunds WJ, Lau CL, Kucharski AJ, Lowe R. Transmission modelling of environmentally persistent zoonotic diseases: A systematic review. Lancet Planet Health. 2021; 5: e466–e478.

69. Saeed M, Al-Khalaifah H, Al-Nasser A, Al-Surrayai T. Feeding the future: A new potential nutritional impact of Lactiplantibacillus plantarum and its promising interventions in future for poultry industry. Poult Sci. 2025; 104: 105130.

70. Safwa SM, Ahmed T, Talukder S, Sarker A, Rana MR. Applications of non-thermal technologies in food processing industries: A review. J Agric Food Res. 2024; 18: 100917.

71. Sambaza SS, Naicker N. Contribution of wastewater to antimicrobial resistance: A review article. J Glob Antimicrob Resist. 2023; 34: 23–29.

72. Sampers IA, Jacxsens L, Lining PA, Marcelis WJ, Dumoulin A, Uyttendaele M. Performance of food safety management systems in poultry meat preparation processing plants in relation to Campylobacter spp. contamination. J Food Prot. 2010; 73: 1447–1457.

73. Samreen, Ahmad I, Malak HA, Abulreesh HH. Environmental antimicrobial resistance and its drivers: A potential threat to public health. J Glob Antimicrob Resist. 2021; 27: 101–111.

74. Olugbenga OS, Adeleye PG, Oladipupo SB, Adeleye TA, John KI. Biomass-derived biochar in wastewater treatment: A circular economy approach. Waste Manag Bull. 2024; 1: 1–14.

75. Senadheera SS, Withana PA, You S, Tsang DCW, Hwang SY, Ok YS. Sustainable biochar: Market development and commercialization to achieve ESG goals. Renew Sustain Energy Rev. 2025; 217: 115744.

76. Shao B, Liu Z, Tang L, Liu Y, Liang Q, Wu T, et al. The effects of biochar on antibiotic resistance genes removal during different environmental governance processes: A review. J Hazard Mater. 2022; 435: 129067.

77. Sharma G, Dey TK, Hazarika RA, Shome BR, Shome R, Singh VP, et al. Knowledge and practices related to antibiotics among poultry producers and veterinarians in two Indian states. One Health. 2024; 18: 100700.

78. Silveira RF, Roque-Borda CA, Vicente EF. Antimicrobial peptides as a feed additive alternative to animal production, food safety and public health implications: An overview. Anim Nutr. 2021; 7: 896–904.

79. Silvestrini MM, Smith NW, Sarti FM. Evolution of global food trade network and its effects on population nutritional status. Curr Res Food Sci. 2023; 6: 100517.

80. Simbine-Ribisse EO, Bila NM, Manhiça AJ, Macuamule CJ, Bragotto APA. Antibiotic residues in dairy products in Africa: A systematic review. Food Chem Adv. 2024; 5: 100822.

81. Singh R, Kim K. Environmental occurrence of antibiotic resistance, control measures and challenges in finding therapeutic management. Emerg Contam. 2025; 11: 100440.

82. Singh S, Kriti M, KS A, Sharma P, Pal N, Sarma DK, et al. A one health approach addressing poultry-associated antimicrobial resistance: Human, animal and environmental perspectives. Microbe. 2025; 7: 100309.

83. Singh VP, Jha D, Rehman BU, Dhayal VS, Dhar MS, Sharma N. A mini-review on the burden of antimicrobial resistance and its regulation across one health sectors in India. J Agric Food Res. 2024; 15: 100973.

84. Song T, Teng H, Li Y, Wang J, He C, Li B, et al. Exploring potential ecological risks of antibiotic–resistance genes in soil–plant systems caused by manure application. Sustain Horiz. 2025; 14: 100128.

85. Stringer LC, Fraser EDG, Harris D, Lyon C, Pereira L, Ward CFM, et al. Adaptation and development pathways for different types of farmers. Environ Sci Policy. 2020; 104: 174–189.

86. Sun Z, Hong W, Xue C, Dong N. A comprehensive review of antibiotic resistance gene contamination in agriculture: Challenges and AI-driven solutions. Sci Total Environ. 2024; 953: 175971.

87. Tang S, Li T, Zheng Y. Effects of higher minimum quality standards on food safety: Evidence from criminal cases found in China's court documents. J Food Prot. 2023; 86: 100098.

88. Tcheou PB, Bedekelabou AP, Adjei-Mensah B, Kpomasse CC, Talaki E, Salou M. Antibiotic use and residue detection in guinea fowl eggs in rural Togo: An assessment of practices and risks. Vet Anim Sci. 2025; 28: 100448.

89. Torres MC, Vieira TR, Cardoso MRI, Siqueira FM, Borba MR. Perception of poultry veterinarians on the use of antimicrobials and antimicrobial resistance in egg production. Poult Sci. 2022; 101: 101987.

90. Uddin TM, Chakraborty AJ, Khusro A, Zidan BRM, Mitra S, Emran TB, et al. Antibiotic resistance in microbes: History, mechanisms, therapeutic strategies and future prospects. J Infect Public Health. 2021; 14: 1750–1766.

91. Vercelli C, Amadori M, Gambino G, Re G. A review on the most frequently used methods to detect antibiotic residues in bovine raw milk. Int Dairy J. 2023; 144: 105695.

92. Vinothkanna A, Dar OI, Liu Z, Jia AQ. Advanced detection tools in food fraud: A systematic review for holistic and rational detection method based on research and patents. Food Chem. 2024; 446: 138893.

93. Wang F, Xiang L, Leung KSY, Elsner M, Zhang Y, Guo Y, et al. Emerging contaminants: A One Health perspective. Innovation. 2024; 5: 100612.

94. Wang J, Deng L, Chen M, Che Y, Li L, Zhu L, et al. Phytogenic feed additives as natural antibiotic alternatives in animal health and production: A review of the literature of the last decade. Anim Nutr. 2024; 17: 244–264.

95. Wen J, Yao X, Geng S, Zhu L, Jiang H, Hu L. Urinary antibiotic levels and risk of overweight/obesity in preschool children: A biomonitoring-based study from eastern China. Ecotoxicol Environ Saf. 2024; 269: 115733.

96. Wickramasuriya SS, Ault J, Ritchie S, Gay CG, Lillehoj HS. Alternatives to antibiotic growth promoters for poultry: A bibliometric analysis of the research journals. Poult Sci. 2024; 103: 103987.

97. Yang W, Li J, Yao Z, Li M. A review on the alternatives to antibiotics and the treatment of antibiotic pollution: Current development and future prospects. Sci Total Environ. 2024; 926: 171757.

98. Yuan Y, Chen P, Li Y, Cheng J, Yan X, Luo C, et al. Changes in antibiotic residues and the gut microbiota during ciprofloxacin administration throughout Silkie chicken development. Poult Sci. 2023; 102: 102267.

99. Zhang T, Nickerson R, Zhang W, Peng X, Shang Y, Zhou Y, et al. The impacts of animal agriculture on One Health: Bacterial zoonosis, antimicrobial resistance, and beyond. One Health. 2024; 18: 100748.

100. Zhang Y, Cheng D, Xie J, Zhang Y, Wan Y, Zhang Y, et al. Impacts of farmland application of antibiotic-contaminated manures on the occurrence of antibiotic residues and antibiotic resistance genes in soil: A meta-analysis study. Chemosphere. 2022; 300: 134529.