Asian Australas. J. Biosci. Biotechnol. 2025, 10(3), 64-76; https://doi.org/10.3329/aajbb.v10i3.84039

Asian-Australasian Journal of Bioscience and Biotechnology
ISSN 2414-1283 (Print) 2414-6293 (Online)
https://www.ebupress.com/journal/aajbb/

Review

An overview of antimicrobial residues in animal-originated food products in developing countries

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Received: 03 August 2025/Accepted: 29 October 2025/Published: 10 November 2025

Abstract: Antimicrobial residues in food products of animal origin represent a significant public health concern that requires careful consideration due to their harmful effects on consumer health. The presence of antibiotic residues in animal-derived food poses challenges for international trade involving animals and their products. Public health issues related to antibiotic residues in food include the emergence and spread of antimicrobial resistance (AMR), allergic reactions, cancer risks, genetic mutations, birth defects, bone marrow damage, and disruption of normal gut microbiota. The indiscriminate use of antibiotics in livestock can lead to residue levels that exceed permissible limits, resulting in adverse health effects for humans. Limiting antibiotic use is crucial for the safety of animal products. This review examines the administration of antibiotics to food animals, the presence of antibiotic residues in animal-origin foods, and the various factors that influence these residue levels in animal-derived food products in developing countries. It underscores the urgent need for improved regulatory control and surveillance of antibiotic use in food-producing animals to ensure public health safety. The findings highlight the importance of strengthening residue monitoring systems, enforcing withdrawal periods, and promoting responsible antibiotic stewardship to reduce contamination in animal-derived foods.

Keywords: antimicrobial agents; food safety; veterinary drug misuse; public health risk; residue monitoring

1. Introduction

The presence of antimicrobial residues in animal-origin food products is a growing public health and food safety concern, particularly in developing countries where regulatory frameworks and monitoring systems are often inadequate. Antibiotics are extensively used in livestock and poultry farming to treat and prevent various ailments, such as gastrointestinal problems, bacterial infections, mastitis, respiratory illnesses, and arthritis (Hosain *et al.*, 2021). In countries like Bangladesh, Bhutan, Pakistan, India, Indonesia, Nepal, Sri Lanka, and Thailand, this usage may be influenced by disease prevalence, disease prevention, growth promotion, and treatment (Arsène *et al.*, 2022).

A major issue is that farmers often do not adhere to the required withdrawal period after administering antibiotics before selling milk, eggs, or meat. As a result, these foods frequently contain leftover drug residues (Hosain *et al.*, 2022). Residues in meat, milk, eggs, and other animal-origin food products can arise from various factors, including failure to observe withdrawal periods, excessive dosages, contamination of animal

feed, use of unlicensed antibiotics, incorrect routes of administration, application of drugs in unintended species, and lack of veterinary oversight (Destaw and Ayehu, 2022). The persistence of antibiotic residues in food poses significant health risks. One of the most critical concerns is antimicrobial resistance (AMR), which reduces the effectiveness of antibiotics in treating human infections and contributes to the global health crisis of drug-resistant pathogens. Additionally, long-term exposure to antibiotic residues can lead to allergic reactions, toxicity, disruptions to the human gut microbiome, bone marrow destruction, and reproductive problems (Treiber and Beranek-Knauer, 2021). Beyond health risks, the presence of these residues affects international trade, as products from developing nations often fail to meet stringent global food safety standards, resulting in economic losses and restricted market access (Mgonja and Paul, 2023).

Despite the growing awareness of antibiotic residue contamination, many developing countries face significant challenges in regulating and controlling its occurrence (Abou-Jaoudeh *et al.*, 2024). Weak enforcement of policies, limited laboratory infrastructure for residue detection, and inadequate awareness among farmers and consumers exacerbate the problem. Addressing these challenges requires a multifaceted approach, including strengthening regulatory frameworks, improving surveillance systems, adopting advanced residue detection technologies, and promoting responsible antibiotic use in food production through education and training.

This paper provides a comprehensive overview of antibiotic residues in animal-derived food products in developing countries. It explores their sources, prevalence, associated health and economic implications, regulatory challenges, and potential mitigation strategies. By identifying key gaps and proposing solutions, this study aims to contribute to ongoing efforts to enhance food safety, safeguard public health, and promote sustainable livestock practices in developing countries.

2. Review method

In this review, relevant information on the topic was gathered through a literature search using electronic databases such as Science Direct, Google Scholar, PubMed, and BASE. Published studies concerning antimicrobial residues in animal-derived foods were included. The search was conducted from December 2024 to July 2025, focusing on original scientific articles published in English between 1999 and 2025. Most articles utilized for this review were published from 2015 onward. The following keywords were employed to find scientific literature: antimicrobial, antibiotic, veterinary drugs, drug residues, public health impact of drug residues, meat, poultry, eggs, beef, milk, and animal products. All collected records were saved, and articles deemed irrelevant to this review or written in languages other than English were excluded. Publications that included data on antimicrobial residues in the abstract were selected for initial examination. All gathered scientific works addressing antimicrobial drug residues and their implications were included. Overall, approximately 50 published pieces of literature related to this subject were utilized.

3. Use of antimicrobials in food animals

Antimicrobial agents commonly used in developing countries for food-producing animals include beta-lactams, tetracyclines, macrolides, sulfonamides, aminoglycosides, fluoroquinolones, lincosamides, and cephalosporins (Hosain *et al*., 2021). These antibiotics serve multiple purposes, including treating existing infections in animals, preventing potential infections—especially in intensive farming conditions—and enhancing growth rates and feed efficiency.

Recent studies have shown that excessive use of antibiotics can lead to residues in animal products (Destaw and Ayehu, 2022). Milk, meat, eggs, and other dairy products containing antibiotic residues that exceed the maximum residue limits (MRLs) may pose serious health risks to consumers (Mesfin *et al.*, 2024). A significant level of antimicrobial residues has been found in broiler liver (79%) and meat (62%) samples collected from live bird markets, with oxytetracycline being the most prevalent contaminant (Neogi *et al*., 2020).

4. Country-specific antimicrobial uses in livestock and poultry farms

Bangladesh: In Bangladesh, antibiotics are primarily used to treat illnesses in livestock. The most commonly prescribed antibiotics are streptomycin–penicillin (31%), followed by sulfadimidine (14%), amoxicillin (11%), a gentamicin–sulfadiazine–trimethoprim combination (9%), and tylosin (1%) (Bhowmik *et al.*, 2017). Approximately 94.16% of poultry farmers administer antibiotics on their farms for disease management and to enhance egg production (Ferdous *et al.*, 2019), while over 70% of the total antibiotics used in food-producing animals are produced by local pharmaceutical companies (Anesary *et al.*, 2014). About 18.89% of poultry feed samples contain antibiotic residues, predominantly oxytetracycline, due to its widespread use in production (Alam *et al.*, 2021).

Bhutan: Antimicrobial use in animal production is limited. Commonly used antibiotics include penicillin, tetracycline, and sulfonamides (Hosain *et al.*, 2021). Animals with wounds and diarrhea are regularly treated with broad-spectrum antibiotics such as penicillin, tetracyclines, trimethoprim + sulfa, and sulfonamides. Prescriptions for antibiotics fall under the AWaRe access group (45%–70%) and the watch group (up to 25%) (Villanueva-Cabezas *et al.*, 2021).
India: Antibiotics are frequently used for both therapeutic and preventive purposes in milk-producing animals. In 2010, India accounted for approximately 3% of global antibiotic use in food animal production, ranking fourth worldwide (Islam *et al.*, 2024).
Indonesia: Tetracycline and amoxicillin are among the most commonly used antibiotics, with 28.7% of farmers reporting their use. Other antibiotics include benzylpenicillin, gentamicin, ciprofloxacin, oxytetracycline, enrofloxacin, and doxycycline (Islam *et al.*, 2024).
Nepal: Over 70% of veterinary medicine sales occur through paraprofessionals or retail establishments. The top antibiotics used include tetracycline, enrofloxacin, neomycin-doxycycline, levofloxacin, colistin, and tylosin (Islam *et al.*, 2024). The overall prevalence of antibiotic use was 90%, according to research conducted on 30 large broiler poultry farms, of which 27 utilized antibiotics. Twenty-one (78%) farms used antibiotics for therapeutic purposes, while six (22%) farms used them as a preventative measure. They employed seven different types of antibiotics from six distinct classes in their investigation. The most commonly used antibiotics for treatment were tylosin (47%) and colistin (47%), with dual antibiotic regimens of neomycin and doxycycline (33%) (Koirala *et al.*, 2021).
Sri Lanka: The most frequently used antibiotic is tetracycline. Combinations of sulfa-trimethoprim, cloxacillin, bacitracin, and neomycin are commonly employed to treat mastitis (Islam *et al.*, 2024).
Thailand: Antimicrobial usage has rapidly increased in livestock, similar to trends in other countries in the region (Hosain *et al.*, 2021).

5. Causes of antibiotic residues in animal-origin foods

Animal-derived food items may contain antibiotic residues due to the inappropriate use of antibiotics in animal feed, neglect of withdrawal periods, unlawful antibiotic applications, and the use of antibiotics as growth promoters, along with inadequate cleaning of equipment used for mixing or administering medications (Otaigbe and Elikwu, 2023). The indiscriminate and irrational use of antibiotics without adhering to proper withdrawal periods can lead to high levels of drug residues (Islam *et al*., 2019a). Due to ineffective drug regulation by governmental authorities, there is limited information regarding the rational use of veterinary medications. In developing countries, food animals are often slaughtered without any screening, and there are no established control mechanisms to protect consumers from consuming meat and dairy products that may contain harmful drug residues (Toghroli *et al*., 2024). Figure 1 illustrates the flow of antimicrobial residues in foods of animal origin resulting from the use of antimicrobial agents from various sources in developing countries.

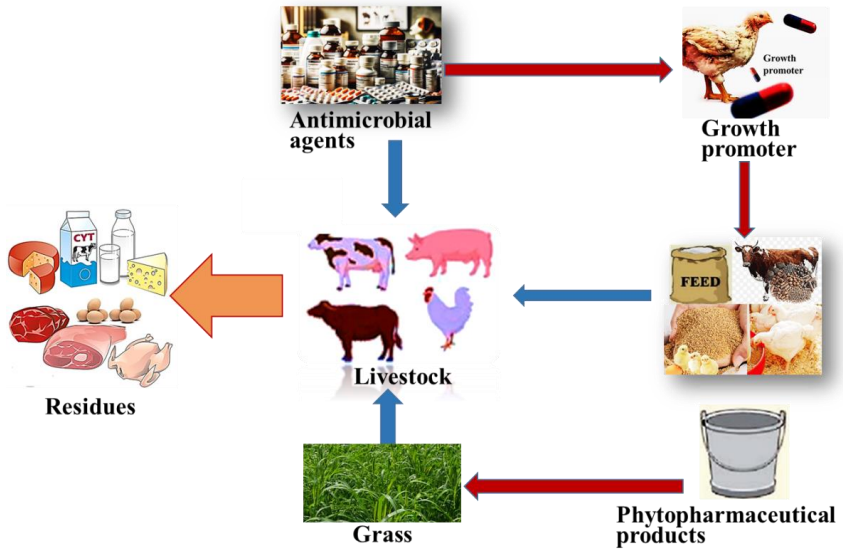

Figure 1. Schematic representation of antimicrobial use in livestock and the transmission pathways of antimicrobial residues into animal-derived food products and the environment.

The illustration depicts the primary routes through which antimicrobials enter the food chain during production, contributing to the accumulation of residues in animal-derived commodities. Antimicrobials are administered to livestock for treatment, prevention, and growth promotion (Niranjan *et al*., 2023). They are commonly used as additives in water and animal feed for livestock, including poultry, cattle, and swine. Residues of these substances remain on edible animal products, such as meat, milk, and eggs, which then enter the human food chain (Hosain *et al*., 2021). Additionally, expelled antimicrobial agents can contaminate the environment—such as soil, pastures, and water bodies—creating a feedback loop that re-exposes animals and facilitates the persistence and spread of antimicrobial residues and resistance (Vidovic *et al*., 2020).

Among the antibiotics banned in human medicine but still used in veterinary settings, with no permissible extra-label applications in any food-producing animal species, are chloramphenicol, fluoroquinolone-class antibiotics, medicated feeds, nitrofuran agents like furazolidone and nitrofurazone, and glycopeptides such as vancomycin (Ghimpețeanu *et al.*, 2022). Furthermore, the prevalence of counterfeit or substandard antibiotics, improper disposal of unused antibiotics, inadequate wastewater treatment systems, and a lack of knowledge regarding the proper use of antibiotics and their implications may lead to increased residue levels of antibiotics in animal-derived food products.

6. Residues of antimicrobials in food products of animal origin

6.1. Meat

Due to their high nutrient composition and appealing sensory characteristics, meat and meat products hold a unique place in our diets. However, these products can pose health risks as they are susceptible to contamination and spoilage (Das *et al.*, 2019; Biswas and Mandal, 2020). This concern intensifies when meat items contain drug residues that exceed acceptable limits, as such residues can adversely affect public health based on the maximum residue levels found in animal tissues (Ramatla *et al.*, 2017; Treiber and Beranek-Knauer, 2021). Tetracyclines, ciprofloxacin (a type of quinolone), and amoxicillin (a β-lactam) have been detected in domestic chicken muscle tissue (Patel *et al.*, 2018). An independent study utilizing enzyme-linked immunosorbent assay (ELISA) revealed that 51.1% of beef and poultry samples tested positive for quinolone antibiotic residues (Er *et al.*, 2013). Additionally, ultra-performance liquid chromatography combined with high-resolution quadrupole time-of-flight mass spectrometry (QToF) found that 28.6% of Chinese animal and poultry meat samples contained antibiotics, including enrofloxacin and trimethoprim, which exceeded the MRLs (Wang *et al.*, 2017).

Highly resistant pathogenic microbes have been identified in the meat of various animals, exhibiting resistance to amoxicillin, penicillin, chloramphenicol, erythromycin, and cefradine (Matubber *et al.*, 2021). Residues of tetracycline (25.3%), sulphanilamide (18%), streptomycin (34%), and ciprofloxacin (56%) were found in muscle samples from beef, pork, and chicken. The presence of antimicrobials such as tetracyclines, β-lactams, and sulphonamides (76.4%) is attributed to the use of veterinary medications without adhering to the prescribed withdrawal periods, along with a lack of awareness regarding the negative impacts of these antimicrobials (Agmas and Adugna, 2018).

6.2. Milk

Milk is consumed globally and holds significant nutritional and commercial value. While milk and dairy products are nutritious and beneficial, they can contain residues from medications that may pose risks to public health (Lourenco *et al.*, 2020). These residues can enter milk through various means, including contaminated feed and water, improper veterinary drug use, failure to withdraw milk correctly, inadequate milk collection, and poor processing practices (Shaikh and Patil, 2020). The primary source of antibiotic residues in milk is the negligent use of antibiotics to treat infections in animals. Additionally, some antibiotics are used indiscriminately as feed additives, further contributing to the presence of these residues in milk and raising potential public health concerns (Sachi *et al.*, 2019). These contaminants can persist in milk and lead to significant adverse health consequences for consumers, including allergic reactions and cancer (Parmar *et al.*, 2021).

6.3. Eggs

The primary groups of antibiotic residues identified in egg samples include coccidiostats, anticoccidials, sulphonamides, nitrofurans, β-lactams (such as amoxicillin), and the macrolide class. This indicates that consuming eggs may pose a risk to public health, particularly when the levels of antibiotic residues exceed the MRLs. The necessity for antibiotic use may be critical due to the increasing global production of poultry eggs to meet the rising demand for food and nutrition from the growing population. Additionally, the indiscriminate use of antibiotics helps maintain productivity on poultry farms (Bhuiyan *et al.*, 2021). Consequently, stringent

guidelines should be established to ensure the responsible and limited use of antibiotics in poultry management (Owusu-Doubreh *et al.*, 2023). A study on the residues of veterinary drugs in chicken eggs demonstrated the presence of tetracycline (33.6%), quinolones (24.7%), and sulphonamides (4.8%) (Yang *et al.*, 2020). Furthermore, using HPLC–QTOF-MS, residues of fipronil sulphone, sulphamonomethoxine, and sulfachloropyridazine were detected in poultry eggs (Hou *et al.*, 2020).

7. Residual limits of major antibiotics used in poultry and livestock

To ensure food safety, several regulatory agencies establish MRLs for antibiotics in poultry and cattle (Table 1). These limits specify the highest legally permitted levels of antibiotic residues in animal-derived food products. Table 1 presents the MRLs for selected antibiotics, as defined by the Codex Alimentarius Commission, Commission Regulation (EU) No 37/2010, the USA (FDA), and other national authorities.

Table 1. Maximum residue limit (MRL) levels of different antibiotics in livestock and poultry products (µg/kg or ppb).

Antibiotic	Meat (muscle)	Liver	Kidney	Milk	Eggs	Regulatory source
Penicillin	50	50	50	4	4	Codex, EU, FDA
Tetracycline	100	300	600	100	200	Codex, EU, FDA
Streptomycin	500	1000	2000	200	-	Codex, EU
Erythromycin	200	250	500	40	150	Codex, EU, FDA
Chloramphenicol	Banned	Banned	Banned	Banned	Banned	Worldwide Ban
Fluoroquinolones	100	200	300	50	50	Codex, EU, FDA
Macrolides (e.g., Tylosin)	100	300	500	50	50	Codex, EU, FDA
Sulfonamides	100	100	100	10	100	Codex, EU, FDA
Nitrofurans	Banned	Banned	Banned	Banned	Banned	Worldwide Ban
Cephalosporins	100	200	400	50	50	Codex, EU, FDA

8. Antimicrobial residues in dairy and poultry products in developing countries

The prevalence of antimicrobial residues in dairy (Table 2) and poultry products (Table 3) in developing countries is a growing concern due to its implications for public health and AMR. Studies indicate that a significant proportion of milk, eggs, and poultry meat contain antibiotic residues that exceed permissible limits. This issue primarily arises from the misuse of veterinary drugs, inadequate withdrawal periods, and weak regulatory enforcement. The widespread and indiscriminate use of various antibiotics in poultry farming raises significant concerns about drug residues in edible tissues, public health risks, and the development of AMR (Hasan *et al*., 2025). Commonly detected antibiotics in developing countries include tetracyclines, sulfonamides, beta-lactams, aminoglycosides, macrolides, and fluoroquinolones.

Table 2. Prevalence of antimicrobial residues in dairy products.

Country	Prevalence of antimicrobial residues	Common antibiotics detected	References
Bangladesh	Research conducted on 159 animal-derived food samples revealed that approximately 30.81% contained antibiotic residues. Specifically, amoxicillin and ampicillin residues were found in 7.14% and 4.76% of meat samples, respectively, surpassing established MRLs. Another study demonstrated that both pasteurized and raw cow's milk contain residues of enrofloxacin and levofloxacin. It is observed that some pasteurized milk samples contain oxytetracycline, levofloxacin, and enrofloxacin at higher levels than the MRL of 121 µg/L.	Amoxicillin, ampicillin, enrofloxacin, levofloxacin, oxytetracycline	Rahman *et al.* (2024)
Bhutan	Compared to other South Asian nations, Bhutan has significantly lower rates of antibiotic consumption in its livestock population. One study found that the livestock in Bhutan consumed antibiotics at an average of 3.83 mg/PCU.	Aminoglycosides, Amphenicols, cephalosporins, Penicillin, Sulphonamids, Trimethoprim, Tetracyclines	Villanueva-Cabezas *et al.* (2021)

Table 2. Contd.

Country	Prevalence of antimicrobial residues	Common antibiotics detected	References
India	A nationwide survey by FSSAI found that over 5% of milk samples contained antibiotic residues above the MRLs. Another study in Punjab revealed that 26.7% of milk samples were positive for β-lactam antibiotic residues (Kumar et al., 2016). Another study showed that, in Tamil Nadu, 13% of milk samples tested positive for antimicrobial residues (Rani *et al*., 2017).		Kurjogi *et al.* (2019); Mathew and Vyas (2022)
Indonesia	In one study, 203 raw milk samples were collected across Malang, Boyolali, and Padang Panjang. The residues that were found ranged from approximately 12 to over 500 ng/g and included chlor tetracycline (8.37%), tetracycline (7.88%), and oxytetracycline (5.91%). Only 3.45% exceeded MRLs (for chlor-tetracycline), while none of the oxytetracycline or tetracycline samples surpassed MRLs.		Widiastuti *et al.* (2023); Suherman *et al.* (2023)
Nepal	A study was conducted to estimate antibiotic residues in 168 milk samples of cows and buffaloes, and according to the data, gentamicin, streptomycin, and sulphonamide residues were found in 55% (93/168) of the samples, and the sulphonamide residues in the milk samples were higher than the national MRL (mean ppb: 26.44 μg/kg/L).	Gentamicin, streptomycin, sulphonamide	Gompo *et al.* (2020)
Pakistan	In a research study carried out in Faisalabad, Pakistan, over half of the beef and milk samples, specifically 22 (55%), surpassed the allowable maximum residue limit for tetracycline.	Tetracycline	Qamar *et al.* (2023)
Sri Lanka	In national screening, most tested samples across various products were residue-free; however, milk showed moderate contamination, around 16% in testing, with mastitis treatment being a key source. Another study identified that many dairy farmers lacked awareness of antibiotic withdrawal periods, contributing to residues in milk.	Tetracyclines, penicillin, and sulfonamides	Perera *et al.* (2013)
Thailand	In a study involving 263 samples, antibiotic residues were found in 103 (69.59%) of the 148 samples of fresh beef, chicken, and pork obtained from the fresh market. These samples comprised fresh meat (n=12, 100%), fresh chicken (n=18, 85.71%), and fresh pork (n=73, 63.49%). Tetracycline residues were identified in six (13.95%) of the forty-three cow milk samples that were ready for consumption. No tetracycline residue was detected in 72 fresh chicken and pork samples (36 of each) that were marketed as hygienic.	Tetracyclines, penicillin, and sulfonamides	Thanapatcharoen *et al.* (2022)

Table 3. Prevalence of antimicrobial residues in poultry products.

Country	Prevalence of antimicrobial residues	Common antibiotics detected	References
Bangladesh	23.5% of 230 poultry samples (meat, eggs, and feed) tested positive; 35% in broiler meat, 25% in layer meat, 15% in layer eggs, and 30% in duck eggs.	Tetracyclines, quinolones, beta-lactams, sulfonamides, aminoglycosides, macrolides	Sani *et al.* (2023)
Bhutan	Antimicrobial residue data not available	Sulfonamides, tetracyclines, penicillins, aminoglycosides, amphenicols, fluoroquinolones	Gurung *et al.* (2023)
India	One study revealed that 40% of the samples contained antibiotic residues, with concentrations ranging from 3.37 to 131.75 μg/kg. Notably, 22.9% of these samples had residues of a single antibiotic, while 17.1% contained multiple antibiotics.	Tetracyclines, enrofloxacin, ciprofloxacin, fluoroquinolones, neomycin	Waghamare *et al.* (2020)

Table 3. Contd.

Country	Prevalence of antimicrobial residues	Common antibiotics detected	References
Indonesia	Recent studies have reported a decrease in antibiotic residues in poultry products; however, approximately 4.1% to 4.17% of samples contain low concentration tetracycline residues.	Penicillins, Tetracyclines, Macrolides, Aminoglycosides	Bura *et al.* (2024)
Nepal	61.1% of broiler meat samples contain enrofloxacin residues; another study detected antibiotic residues in 8.33% of muscle samples and 13.33% of liver samples. Tetracycline residues were detected in 20% of breast and thigh muscle samples, 24% of kidney samples, and 48% of liver samples in another investigation.	Enrofloxacin and Tetracyclines	Gompo *et al.* (2020)
Pakistan	Studies indicate antibiotic residues in poultry meat, but exact prevalence rates vary. One study revealed that almost all the samples contain low concentrations of tetracycline and ciprofloxacin residues.	Tetracyclines, sulfonamides, quinolones, macrolides, and aminoglycosides	Mund *et al.* (2017)
Sri Lanka	One study revealed that 51.9% of broiler breast muscle samples were positive for enrofloxacin residues and 7% for ciprofloxacin residues.	Ciprofloxacin, enrofloxacin, sulfonamides	Karunarathna *et al.* (2021)
Thailand	Limited publicly available data, but studies suggest antimicrobial residues exist in commercial poultry. One study demonstrated that 12% of chicken meat samples from backyard farms tested positive for tetracycline residues, and 24% of samples contained macrolide, aminoglycoside, and sulfonamide class residues.	Tetracyclines, macrolides, aminoglycosides, sulfonamides	Wongvichayaporn *et al.* (2023)

9. Residual impact of antimicrobials on human health

The presence of antimicrobial residues in animal-origin food products, such as meat, milk, and eggs, raises significant public health concerns (Izah *et al.*, 2025). For instance, the indiscriminate use of colistin in poultry, coupled with insufficient management and regulatory enforcement, poses a considerable risk to public health (Bristy *et al.*, 2019). These residues primarily arise from the use of antibiotics in livestock and poultry farming, intended for disease treatment, prevention, and growth promotion. However, improper usage and inadequate withdrawal periods can result in residues in food products, thereby impacting human health in various ways.

9.1. Development of antimicrobial resistance (AMR)

Continuous exposure to low levels of antibiotics through food consumption can promote the survival and proliferation of resistant bacterial strains, making infections harder to treat and contributing to the global AMR crisis (Endale *et al.*, 2023). This situation leads to increased morbidity, mortality, and healthcare costs. Additionally, the presence of high levels of multidrug-resistant bacteria, such as *E. coli* and *Salmonella*, in food animals and food products serves as a reservoir for resistant genes (Hosain *et al.*, 2021).

9.2. Allergic reactions and toxicity

Some individuals may experience hypersensitivity reactions or allergic responses to antibiotic residues, particularly to beta-lactams (such as penicillins and cephalosporins) and sulfonamides. Severe allergic reactions can lead to anaphylaxis, a life-threatening condition. Additionally, certain antibiotics, like chloramphenicol, have been associated with toxic effects, including bone marrow suppression and aplastic anemia (Bacanlı, 2024). Furthermore, improper use of antibiotics can adversely affect hematological parameters in broilers (Islam *et al*., 2019b). Chronic exposure to antibiotic therapy in mice has shown to result in liver steatosis, glomerular atrophy, and inflammatory cell infiltration in both the liver and kidneys (Islam *et al*., 2025).

9.3. Disruption of gut microbiota

Long-term ingestion of antibiotic residues can disrupt the balance of gut microbiota, potentially leading to digestive issues, weakened immunity, and metabolic disorders (Sadighara *et al.*, 2023). The gut microbiome is

essential for maintaining overall health, and its disruption can contribute to conditions such as inflammatory bowel disease (IBD) and obesity.

9.4. Carcinogenic and mutagenic effects

Certain antibiotics, such as nitrofurans and chloramphenicol, are classified as potentially carcinogenic. Prolonged exposure to these residues may elevate the risk of cancer, genetic mutations, and organ damage, particularly affecting the liver and kidneys (Treiber and Beranek-Knauer, 2021).

9.5. Endocrine disruption and reproductive effects

Certain antimicrobial residues can disrupt hormonal balance, leading to reproductive issues, developmental abnormalities, and endocrine disorders (Hou *et al.*, 2024). For instance, prolonged exposure to hormone-like antibiotic compounds may result in early puberty, reduced fertility, or immune system dysfunction.

10. Strategies for reducing antimicrobial residues in animal-origin food products

In developing nations, the issue of antimicrobial residues is exacerbated by insufficient enforcement of regulations, a lack of educational resources for farmers, and limited access to veterinary care. Discriminatory use of antibiotics, along with adherence to proper withdrawal periods, is effective in combating antibiotic residues (Islam *et al*., 2023). The strategies presented in Table 4 can be implemented to minimize antimicrobial residues in food products derived from animals. Collectively, these strategies highlight the need for integrated policies, collaboration among stakeholders, and increased public awareness to ensure sustainable control of antimicrobial residues in developing countries.

Table 4. Strategies for reducing the amount of antimicrobial residues in animal-originated food products.

Strategies	Challenges	Solution
Strengthening regulations and enforcement	▪ Weak enforcement of drug withdrawal periods. ▪ Limited access to laboratory testing for residues. ▪ Poor tracking of antibiotic sales and use.	▪ **Stronger policies & regulations** ✓ Governments should ban or restrict the use of critical human antibiotics (e.g., colistin) in livestock. ✓ Implement mandatory withdrawal periods and impose penalties for violations. ▪ **Enhancing residue monitoring** ✓ Establish simple, low-cost rapid test kits for antimicrobial residues at slaughterhouses and milk collection centers. ✓ Introduce mobile testing labs in rural areas where lab infrastructure is weak. ▪ **Veterinary oversight on drug sales** ✓ Limit over-the-counter (OTC) antibiotic sales and require prescriptions for use. ✓ Train local para-veterinarians to ensure responsible antibiotic use in remote areas. ▪ **Consumer awareness campaigns** ✓ Educate the public through radio, social media, and posters in markets about the dangers of antimicrobial residues.
Training farmers on responsible antibiotic use	▪ Many farmers lack knowledge about withdrawal periods and proper drug usage. ▪ Antibiotics are misused for growth promotion or as a substitute for good farm management.	▪ **Community-based training programs** ✓ Conduct regular farmer training sessions through agricultural extension officers. ✓ Use local languages and simple, visual guides to explain antibiotic use and withdrawal periods. ▪ **Demonstration farms and role models** ✓ Establish model farms that practice responsible antibiotic use to inspire local adoption. ✓ Identify and train progressive farmers who can share best practices with their communities. ▪ **Record-keeping made simple** ✓ Introduce easy-to-use antibiotic record books to help farmers track drug use and withdrawal periods.

Table 4. Contd.

Strategies	Challenges	Solution
Improving farm management & disease prevention	▪ Poor hygiene and overcrowding increase disease outbreaks, leading to excessive antibiotic use. ▪ Limited access to vaccines results in preventable infections being treated with antibiotics.	▪ **Biosecurity and hygiene improvement** ✓ Teach farmers simple biosecurity steps, like handwashing before handling animals and separating sick animals. ✓ Promote clean water and proper waste disposal to minimize disease risk. ▪ **Affordable vaccination programs** ✓ Partner with NGOs or government programs to subsidize vaccines for small-scale farmers. ✓ Encourage local vaccine production to reduce costs. ▪ **Use of herbal alternatives and probiotics** ✓ Train farmers to use affordable plant-based treatments (e.g., garlic, neem, and turmeric) for mild infections. ✓ Introduce probiotic supplements to improve gut health and reduce the need for antibiotics.
Establishing low-cost residue testing & compliance incentives	▪ Residue testing infrastructure is expensive and inaccessible in rural areas. ▪ Farmers are not incentivized to follow withdrawal periods.	▪ **Introducing on-farm test kits** ✓ Use low-cost rapid screening tests (e.g., dipstick tests for milk residues). ✓ Train milk collectors and slaughterhouse workers to reject contaminated products. ▪ **Market incentives for residue-free products** ✓ Establish "Antibiotic-Free Certification" for farmers who comply with withdrawal periods. ✓ Offer higher prices or priority market access for certified residue-free milk, eggs, and meat. ✓ Encourage supermarkets and restaurants to prefer residue-free products. ▪ **Slaughterhouse and dairy collection monitoring** ✓ Require antibiotic residue checks before meat is sold or milk is processed. ✓ Government can fund periodic residue testing to ensure compliance.
Increasing access to veterinary services in rural areas	Few veterinarians are available in rural areas, leading to self-medication by farmers. Farmers often use antibiotics incorrectly because they lack guidance.	▪ **Training and deploying Community Animal Health Workers (CAHWs)** ✓ Train local farmers or veterinary assistants to provide basic animal healthcare and guidance on antibiotic use. ✓ Equip them with standardized treatment guidelines to prevent antibiotic misuse. ▪ **Mobile veterinary clinics and telemedicine** ✓ Use mobile veterinary units to serve remote farmers. ✓ Introduce SMS or app-based veterinary consultations for instant advice. ▪ **Affordable access to professional veterinary services** ✓ Governments or NGOs can subsidize veterinary care to make expert consultations cheaper for small farmers. ✓ Offer group-based veterinary services where multiple farmers share costs.

11. Conclusions

Antibiotic residues in food products derived from livestock remain a significant public health concern in developing countries. Limited regulatory enforcement, the indiscriminate use of antibiotics for therapeutic, prophylactic, and growth-promoting purposes, and inadequate compliance with withdrawal periods contribute to the persistence of residues in meat, milk, and eggs. High prevalence rates reported in various studies highlight gaps in veterinary drug regulation, farmer awareness, and routine monitoring systems. The presence of these residues not only poses direct toxicological risks to consumers but also exacerbates the global challenge of antimicrobial resistance (AMR). Addressing this issue in developing countries requires a multifaceted approach, including strengthening residue surveillance programs, promoting prudent antibiotic use, enhancing farmer

education, and ensuring strict adherence to withdrawal periods. Without decisive action, this problem will continue to threaten food safety, public health, and international trade in animal-derived food products.

Acknowledgements
The authors would like to express their gratitude to the Quality Control Laboratory, Department of Livestock Services, Savar, Dhaka, Bangladesh, and the Department of Microbiology and Hygiene, Bangladesh Agricultural University, Mymensingh, for their continuous academic guidance and institutional support during the preparation of this review. The authors also acknowledge the contributions of researchers and professionals whose works have been referenced and discussed in this article, providing valuable insights into the issue of antimicrobial residues in animal-originated food products in developing countries. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability
All information gathered or analyzed during this review was from studies available in the public domain.

Conflict of interest
None to declare.

Authors' contribution
Md. Zahangir Hosain: Conceptualized and designed the review; S.M. Shariful Islam, Md. Tanvirul Islam, Md. Roisul Momen and Al Arafat: Collected the literature and analyzed the data; Md. Zahangir Hosain, Muhammad Tahsin Abrar and S. M. Lutful Kabir: Drafted and edited the manuscript. All authors have read and approved the manuscript.

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