Antimicrobial Resistance in Foods of Animal Origin in India: A Narrative Review of Implications for Food Safety and Public Health

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ABSTRACT

Antimicrobial resistance (AMR) is a major global public health challenge, and the food chain is increasingly recognized as an important pathway for transmission of resistant microorganisms from animals to humans. In India, extensive use of antimicrobials for therapeutic, prophylactic, and growth-promoting purposes in food-producing animals has raised serious food safety and public health concerns. The aim of this narrative review is to compile data from 2010–2025 on veterinary antimicrobials use, AMR trends and antimicrobial residues in milk, meat, poultry, eggs, and aquaculture products (including the environment) in India, and highlight gaps in surveillance and policy within a One Health approach. Evidence published shows that high levels of antimicrobial resistant pathogens (e.g., E. coli, *Salmonella*, *Campylobacter* and methicillin resistant *Staphylococcus aureus*) occur in animal-derived food with public health risks from both consumption and handling for example, MRSA was detected in 46% raw milk samples and multidrug resistance of over 60% in some poultry isolates). The scaling-up of antimicrobial stewardship in veterinary practice, improved hygiene and biosecurity in the food chain, increasing integrative surveillance for AMR and better intersectoral coordination is essential to protect public health and ensure food safety in India.

Keywords: Antimicrobial Resistance (AMR), One Health, Veterinary Antimicrobial Use, Human, Antimicrobial Residues, Food Safety, Livestock, Antimicrobials.

INTRODUCTION

The Global use of antimicrobials in food-producing animals has increased considerably during the past few decades, largely driven by growth in livestock production and escalating demand for animal protein (Van Boeckel et al., 2015). Global antimicrobial consumption in food animals is projected to rise by 67% between 2010 and 2030, with the fastest growth occurring in low- and middle-income countries (Van Boeckel et al., 2015). This increasing use is a major factor contributing to AMR development and dissemination in animal production, creating risks to both animal and human health through foodborne and environmental transmission pathways (Pokharel et al., 2020).

India, with one of the largest and most diverse animal populations, rapid expansion in commercial poultry production and dominance of smallholder-backyard farming sectors (ICAR 2O21), poses its own set

challenges. Antimicrobials, including antibiotics, are routinely used in food-animal production for prophylactic and growth-promotion purposes without prior veterinary advice or laboratory diagnosis (Mutua et al., 2020). Inadequate farmer knowledge, weak enforcement of drug supply, and unrecorded use are driving for overuse as well as for selection of resistant bacteria, which is a major source of pollutant in foods of animal origin (Mutua et al., 2020).

Recognizing the public health significance of AMR, India has developed a range of policy and regulatory measures aimed at improving food safety and antimicrobial stewardship. The Food Safety and Standards Authority of India (FSSAI) has set maximum residue limits for antimicrobials in foods of animal origin, and encourages hygienic measures, while the National Action Plan on Antimicrobial Resistance (NAP-AMR) advocates a One Health approach encompassing humans, animals, food and environment sectors (Government of India, 2017; Ministry of Health & Family Welfare, 2017). However, challenges exist to ensure actual implementation, routine monitoring along with cross-sector cooperation at the farm, slaughterhouse and retail are significant (Indian Journal of Medical Microbiology, 2023).

This review is an attempt to make a synthesis of the status of AMU and AMR in key animal source food production sectors (poultry, dairy and aquaculture) in India within One Health concept until 2025. It consists of four sections: (1) patterns and levels of antibiotic use in Indian livestock, (2) prevalence of AMR among the main food commodities, (3) implications for human health, and (4) an assessment of extant policy gaps with recommendations looking forward. By combining microbiological and drug residue findings together with recent policy changes, including the new restrictions regarding antibiotic use in food animals from the FSSAI (FAO and ICAR NIVEDI, 2024; FSSAI, 2022, 2024), this review identifies surveillance gaps and areas for action to enhance antimicrobial stewardship and food safety systems in India.

METHODOLOGY

Literature Search Strategy

The review is a narrative review of studies, organized around a structured literature search to summarize evidence on antimicrobial resistance (AMR) in food of animal origin and the public health significance in India. Scientific databases (PubMed, SCOPUS and Google Scholar) were searched for peer-reviewed publications and relevant grey literature from January 2010 to November 2025 (Popay et al. 2006). The search strategy utilized keywords terms like "Antimicrobial Resistance," "Antibiotic Residues," "Food Animals," "Poultry", Dairy, One Health and India. Boolean operators (AND, OR) were used to limit searches ("AMR AND Poultry AND India"). Policy documents, regulations guidelines and reports were extracted from national, and international organizations FSSAI, WHO, FAO (Government of India, 2017; Ministry of Health and Family Welfare, 2017) as well as those pertaining to National Action Plan on AMR.

Inclusion and exclusion criteria

We focused on peer-reviewed original research, review papers and government reports that offered insights into (1) prevalence data, epidemiological studies that reported the isolation of resistant bacteria (e.g., Escherichia coli, Salmonella spp., Staphylococcus aureus) from animal-derived foods (milk, meat, eggs); (2) antibiotic usage patterns in Indian livestock and poultry farming; and (3) policy & control measures to address AMR in India such as India's National Action Plan on AMR (NAP-AMR), food safety regulations. Studies including human beings that did not present an obvious linkage with either animals or food sources were omitted. In addition, studies from other countries (unless needed to provide international context) and ones with uncertain methodology were excluded.

Data synthesis

Information from selected studies was collated and synthesized narratively to identify key trends, surveillance gaps, and policy challenges. The review is organized thematically, discussing resistance patterns by commodity

(poultry, dairy, aquaculture), public health and occupational health impacts, environmental footprints, and One Health policy responses. This approach enabled the integration of diverse evidence to highlight recurring trends, gaps, and priority needs within the Indian One Health framework.

Drivers of antimicrobial consumption: Intensification and projected trends

The usage of veterinary antimicrobials in India mirrors this diversity from backyard and subsistence production of food animals to increasingly industrialized poultry and dairy operations (Mutua et al., 2020). Modeling studies estimate that the consumption of antimicrobial in Indian food animals will rise by more than 300% from increased use between 2010 and 2030, making India one of the highest consumers of antibiotics for use in animals (Van Boeckel et al., 2015). It is estimated that use is several thousand tons per year in poultry, dairy and livestock (Van Boeckel et al., 2015).

Observable data indicate that antimicrobials are used extensively for therapeutic and non-therapeutic purposes, including disease prophylaxis and growth-promotion (Mutua et al., 2020; Chauhan et al., 2020). In addition, reviews and field visits reveal weak compliance with current therapeutic guidelines, fragmentation of regulatory governance among agencies like Bureau of Indian Standards, FSSAI and the animal health regulators), and a scant system for monitoring AMU across production value chains (Sharma et al., 2020; Chakraborty et al., 2024).

Over-the-Counter availability of veterinary antimicrobials is considered a significant factor contributing to misuse (Kumar, et al., 2018). Evidence reveals that farmers commonly buy antibiotics from private vendors and the black market without prescriptions in both rural and peri-urban settings (Mutua et al., 2020). Less access to good veterinarians, perceived high costs of consultation and a delay in receiving professional care all promote self-medication as well as seeking advice from untrained advisers. According to a few surveys involving cattle and poultry farmers from some states, most of whom had acquired drugs without prescription at least once, laws related to drug control are not effectively enforced in India (Nuakala & Tripathi, 2022).

Tetracyclines (especially oxytetracycline), fluoroquinolones (enrofloxacin and levofloxacin), beta-lactam, and penicillin–streptomycin combinations are the most frequently employed antimicrobial classes in food-animal production in India namely that many of them are categorized as critically important for human medicine by WHO (Mutua et al., 2020; Sharma et al., 2020). Improper practices including sub-therapeutic dosing, early termination of therapy along with the improvement in clinical signs, non-compliance of withdrawal periods and routine inclusion of low antibiotic dose(s) feed or water have been described which are prevalent (Nuakala & Tripathi, 2022).

Records on animal health and antimicrobial use are usually poor, particularly in smallholder dairy and small ruminant systems, with the consequence that veterinarians are unable to make evidence-based treatment decisions and authorities cannot monitor usage patterns (Mutua et al., 2020). Antimicrobial usage even in commercial poultry with improved records are reported to be high because of prophylactic drugs being administered as a prevention strategy given the increased stocking density (Kakkar et al., 2017).

Individual behavior is often shaped by the expected actions of peers, which serves as a primary driver of self-interested decision-making (Prabhu et al., 2025). Objectives behavioral studies indicate that many farmers regard antibiotics as fast and reliable solutions to production needs and lack understanding of AMR and its potential long-term impacts--reflecting thus a need to not only address regulatory aspects but also behavioral elements in stewardship (Chauhan et al.,2018).

In conclusion, current evidences indicates that veterinary antimicrobial use in India is guided by an interplay of various factors like easy access to drugs, limited coverage of veterinary care, economic burden to farmers and low knowledge about AMR. This calls for better stewardship practices, farmer's education, and better regulation (Mutua et al., 2020; Sharma et al., 2020; Chakraborty et al., 2024).

Antimicrobial Resistance in Indian Foods of Animal Origin

Overview

The factors such as high antimicrobial usage in Indian livestock and poultry, lack of adherence to the waiting period for withdrawal are some reasons that may lead to a frequent occurrence of AMR residues and resistant bacteria in different milks, meats, fishes or eggs (Mutua et al., 2020; Sharma et al., 2020).

Hence, foods of animal origin thus represent an important bridge between AMU in veterinary medicine and human exposure to AMR. Recent studies reveal multidrug-resistant E. coli, Salmonella, Campylobacter, methicillin-resistant Staphylococcus aureus (MRSA) and extended-spectrum beta-lactamase (ESBL)-producing Enterobacteriaceae in retail products from various parts of India (Sajish et al., 2025).

Table 1. Key recent studies on antimicrobial resistance (AMR) and antibiotic residues in food products of animal origin in India (2020–2025)

Source (year)	Region/State	Commodity/ product	Target organism(s)/ residue type	Key AMR or finding
Fayaz et al., (2023)	Jammu and Kashmir	Raw bovine milk	Staphylococcus aureus (MRSA)	MRSA detected in (46%) in raw milk samples; high resistance to penicillin and cefoxitin reported.
Sajish et al., (2025)	Multiple states (pan-India retail)	Retail poultry meat	Escherichia coli, Salmonella spp: resistance genes (bla, tet, sul)	Systematic review of 32 studies; high resistance to ampicillin, tetracycline, ciprofloxacin, streptomycin; MDR >60% in several species; frequent detection of bla, tet, sul genes.
Hebbal et al. (2020)	Kerala (Palakkad district)	Raw Milk	Oxytetracycline residues	Oxytetracycline detected in market milk; 1.86% of samples exceeded FSSAI maximum residue limits (MRLs).
Mathew et al. (2024)	Multiple states (India)	Table Eggs (shell surface)	Tetracycline resistance gene (tetA, tetB,); indicator bacteria	tetA and tetB detected on eggshells and cutting surfaces; evidence of environmental contamination and potential transmission along the egg supply chain.
Sivaraman et al. (2021)	Nationwide	Farmed fish (aquaculture)	ESBL-Producing Enterobacteriaceae	High prevalence of ESBL-producing Enterobacteriaceae in farmed fish; frequent co-resistance to sulphonamides and other classes.

Abbreviations: MRL: Maximum Residue Limit; ESBL: Extended-Spectrum Beta-Lactamase; MDR: Multidrug-Resistant

Milk and dairy products

Milk has been one of the most investigated animal-source food types for AMR in India, driven by high burden rates of mastitis among dairy animals and common yet empiric use of antibiotics to control it (Singh et al.,

2022; Mutua et al., 2020). Dairy farming is largely characterized by smallholder and subsistence farmers, with limited access to diagnostic services, inadequate regulation on AMU, and often with limited or no veterinary supervision (Sharma et al., 2020; Chauhan et al., 2018).

These bottlenecks may lead to misuse of antimicrobials and consequently higher likelihood for residues and resistant bacteria in raw milk and dairy products. Milk samples have been reported for high rates of detection of beta-lactams, tetracyclines, sulfonamides and fluoroquinolones both in systematic reviews and field studies with frequent non-compliance with Codex or national MRLs especially observed in raw milk from smallholder systems (Mathew et al., 2022; Hebbal et al., 2020). Oxytetracycline and other residues were found beyond permissible limits in approximately 2-13% of market samples as reported by studies from various states (Hebbal et al., 2020, Gaurav et al., 2014). Primary motivators are poor knowledge of withdrawal periods, economic pressures on the need to continue selling milk during treatment and absence of regular testing for residues at the level of farm or automatic collection center (Sharma et al., 2020).

Raw milk and traditional dairy products have been reported from several studies to contain MRSA, with the isolates often being multidrug-resistant (MDR) carrying the methicillin resistance gene (mecA) and the staphylococcal cassette chromosome mec (SCCmec) indicating potential hazards of direct foodborne infections (Gopal and Divya, 2017). It has been found that other resistant organisms such as E. coli, Staphylococcus aureus, and Enterococcus spp., can frequently be isolated from milk and dairy products from various regions of India with resistance to critically important antimicrobials (Sahoo et al., 2023; Vishweswaraiah et al., 2023). Altogether, it reveals that milk and dairy products serve as a vehicle for the spread of resistant pathogens from dairy animals to humans.

Meat and poultry products

Chicken has become an important reservoir of Antibiotic-Resistant Bacteria (ARB) in India, with the expansion of intensive poultry farming and the widespread use of antibiotics for disease prevention, prophylaxis, and growth-promotion (Laxminarayan & Chaudhury, 2016) E. coli and Salmonella are the main microbial pathogens isolated from retail chicken meat studies more than 60% of isolates being frequently labeled as antimicrobial resistant (Sajish et al,2025), with high resistance to ampicillin, tetracycline, ciprofloxacin and streptomycin reported.

Resistome genes from the bla, tet, and sul families, as well as virulence genes like invA and icaA, have frequently been found, suggesting an overlap between resistance and virulence in avian-associated strains (Sajish et al., 2025). Salmonella and E. coli have been detected in retail chicken meat in studies from different parts of India, as well as high levels of resistant Campylobacter spp. (Singh et al., 2021). Resistance is commonly observed against fluoroquinolones, tetracyclines, and third-, fourth-generation cephalosporins which are the most prevalent antimicrobials used in Indian poultry industry (Brower et al., 2017; Laxminarayan & Chaudhury, 2016). Persistent low dose use of antimicrobials in feed or water at high density flocks, imposes a continuous and strong selection pressure allowing the spread of resistant organisms across the poultry value chain to wet markets and retail points (Laxminarayan & Chaudhury, 2016; Singh et al., 2021).

Resistant pathogens have also been found in beef, mutton and pork products, but the data are not as complete as on poultry. It has been reported that a high proportion of ESBL-producing E. coli and Klebsiella spp., respectively, was observed in retail beef samples which poses potential public health risk in a low regulated slaughter environment with poor processing hygiene practices and weak infrastructure for maintaining cold chain (Montso et al., 2019). These conditions encourage contamination of carcasses and is conducive to the growth of bacteria resistant to antibiotics during transport and sale to counteract these problems.

Eggs and other animal products

Evidence on AMR in eggs from India is, however, much more limited but expanding. Studies available have

shown presence of resistant Salmonella spp. on the eggshells, and *Escherichia coli*, indicating that eggs can act as carriers for the spread of resistant bacteria in the food chain (Chousalkar et al., 2010; Mathew et al., 2024). These trends may be associated with the use of antimicrobial in layer production systems, poor farm biosecurity and unclean handling and storage.

Tetracycline resistance genes (tetA and tetB) were found on fresh egg shell and slaughterhouse cutting surfaces suggesting transfer of resistance determinants from production area to processing operations (Mathew et al., 2024). Eggs: High prevalence of multidrug-resistant isolates and *Escherichia coli, Pseudomonas, Acinetobacter,* and *Klebsiella* spp. (Mathew et al., 2024). Resistant organisms and genes have also been found on eggs from backyard, smallholders flocks demonstrating environmental spread of AMR outside intensive commercial systems. While bacteria levels are decreased in eggs and egg dishes during cooking, potential risks of cross-contamination when storing, handling and preparing foods should not be underestimated, especially in informal market places or domestic environments where food safety principles may not always be followed (Chousalkar et al., 2010).

Aquaculture and seafood products

Aquaculture is the fastest growing food producing sector in India and has high usage of antimicrobials, however, many AMR assessments have not focused on it. Indeed, reports from Indian aquaculture farms have identified ESBL genes in Enterobacteriaceae and other resistant bacteria in farmed fish including co-resistance to a variety of drug classes suggesting aquaculture as an emerging dimension on the national AMR landscape (Sivaraman et al., 2021). Reports on network suggest that resistance is well documented in all major terrestrial and aquatic food animal species thus calling for integrated surveillance across the species (FAO/ICAR NIVEDI, 2024). White papers emphasize that the vast majority of antimicrobials used in animals and fish is released into the environment, polluting soil and water resources, with residues in edible products still representing a significant public health threat due to the lack of enforcement of regular monitoring (FAO, 2022; FAO/ICAR NIVEDI, 2024). These results provide evidence for the explicit inclusion of aquaculture in AMR control strategies for foods of animal origin in India.

Strengthening surveillance and control

Monitoring of residue and resistant in foods from animal sources continue to be fragmented and resource poor in the country (FAO & ICAR, 2019; INFAAR, 2023). Gaps in funding, trained technicians and laboratory capacity at the state-level currently restrict systematic testing, while records on antimicrobial use are generally lacking for most poultry farms. To enhance surveillance, India requires structured periodic cross-sectional testing for milk, meat, eggs and fish; systematic pathogen isolation from farms, slaughterhouses and markets; and uniform sampling protocols across the country. Better sanitation and biosecurity are also critical as poor hygiene favors the spread of resistance (Mutua et al., 2020). Linking foodborne AMR surveillance to national human AMR networks would allow comprehensive risk assessment and interventions (FAO & ICAR, 2019).

Policy measures and one health application

High burden of AMR among food-producing animals in India links agriculture, veterinary services, food safety and environment and public health. "To tackle this issue, the One Health approaches which harmonize stringent legislations with intersectoral enforcement setup (FAO, 2016), are warranted" (Mutua et al., 2020). The National Action Plan on AMR India (2017–2021) sets a pathway however, progress reviews reveal its sluggish implementation in the veterinary and food safety domains due to meagre budget allocation, inadequate state level coordination and failure to introduce animal food data into national AMR reporting (FAO & ICAR, 2019).

In October 2024, FSSAI notified the Food Safety and Standards (Contaminants, Toxins and Residues) First Amendment Regulations, 2024, prohibiting specific antibiotics (including nitrofurans, nitroimidazoles,

carbadox, and combinations containing chloramphenicol, colistin, and streptomycin) during any production stage of milk, meat, poultry, and aquaculture, with full enforcement planned by April 2025 (FSSAI, 2024).

Policy will be successful only if implemented with smallholders and the informal sector where data are lacking (Laxminarayan et al., 2016). Enhanced colistin compliance is crucial, and usage limitations should also apply to other critically important antimicrobials. Mandating veterinary prescriptions for all animal antibiotic use and eliminating over-the-counter sales are critical steps in combating misuse. Strong surveillance and data sharing systems are required to link ICAR FSSAI residue/ resistance data with human AMR networks for integrated risk analysis and evidence-based regulation (FAO & ICAR, 2019).

Economic and social policies can drive behavior change toward responsible production. Certification programs rewarding antibiotic stewardship, subsidies for vaccines and improved husbandry, and targeted capacity building for smallholders can prevent livelihood risks from tighter regulation (CII & FACE, 2025; Mutua et al., 2020). In a context of dispersed responsibilities in such institutions, the creation of an integrated inter-ministerial coordination mechanism for AMR with legislative power and dedicated budget would reinforce NAP AMR implementation.

From an operational standpoint, a One Health approach would involve organized coordination among national ministries/ authorities (FSSAI, ICAR) and the state government through joint surveillance- investigation teams to follow priority resistant organisms (Salmonella spp., E. coli, Campylobacter spp., MRSA), as well as resistance genes along food chain including environmental monitoring of water sources (FAO & ICAR 2019). Antimicrobial stewardship programs with prescriptive guidelines and education strategies for producers and veterinarians along with awareness activities through animal husbandry/health agencies are crucial to educate policy makers about responsible antimicrobial use (FAO & WHO, 2023).

Critical Knowledge and Implementation Gaps

This review identifies four key gaps hindering effective AMR control in food animals:

1. Fragmented surveillance: Livestock, food, human health, and environmental data are collected separately without linked systems.

2. Informal sector knowledge gap: Smallholder dairying and backyard poultry lack objective data on antimicrobial use and resistance profiles.

3. Under-characterized environmental dimension: Resistance elements in water, soil, and biofilms are scarcely quantified.

4. Local infrastructure constraints: Shortages of trained staff and laboratory capacity at state level affect surveillance and enforcement.

Research priorities

Future work must integrate evidence generation with practical policy translation. Critical priorities include establishing longitudinal studies in smallholder dairy and backyard poultry to profile antimicrobial use and resistance emergence over time; environmental mapping of resistance pathways in high-intensity livestock and aquaculture areas using culture-dependent and molecular tools; economic studies quantifying health and social costs of foodborne AMR to support investment decisions; and robust intervention evaluations of vaccination, biosecurity, and stewardship training to identify cost-effective models (FAO, 2016). Research should leverage FAO/WHO Codex frameworks to integrate foodborne AMR monitoring, targeting smallholder and informal systems where data gaps are largest (FAO & WHO, 2023).

CONCLUSION

AMR in India's food of animal origin is a multi-faceted One Health problem. While progress has been made in documenting AMR patterns and establishing policy frameworks like NAP-AMR and recent FSSAI regulations, major gaps persist in integrated surveillance, enforcement, and smallholder support. Strengthening veterinary antimicrobial stewardship, enhancing hygiene from farm to retail, and having strong One Health governance structures will be indispensable for mitigating AMR risks. Converting existing evidence into well-resourced action is essential for preserving the utility of antimicrobials and protecting public health in India.

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