JWPR
Journal of World's Poultry Research

2026, Scienceline Publication
J. World Poult. Res. 16(1): 110-126, 2026
Research Paper
DOI: https://dx.doi.org/10.36380/jwpr.2026.12
PII: S2322455X2600012-16

ISSN: 2322-455X

Development of Antimicrobial Resistance in Layer Chicken Farms in Indonesia: A Review

I Made Mahapurta[1], Kadek Karang Agustina[2]*, and I Nengah Kerta Besung[3]

[1]*Master's Student in Veterinary Medicine, Faculty of Veterinary Medicine, Udayana University, PB. Sudirman St. Campus Denpasar, 80234, Bali, Indonesia*
[2]*Department of Veterinary Public Health, Faculty of Veterinary Medicine, Udayana University, PB. Sudirman St. Campus Denpasar, 80234, Bali, Indonesia*
[3]*Department of Microbiology, Faculty of Veterinary Medicine, Udayana University, PB. Sudirman St. Campus Denpasar, 80234, Bali, Indonesia*

*Corresponding author's E-mail: k.agustina@unud.ac.id

Received: December 22, 2025, Revised: January 20, 2026, Accepted: February 29, 2026, Published: March 31, 2026

ABSTRACT

Layer farming plays a vital role in providing animal-derived food products. Increased production raises concern about antimicrobial resistance (AMR), mainly due to widespread and indiscriminate use of antibiotics as growth promoters and prophylactic therapeutics. The present study aimed to investigate the development and risk factors associated with AMR in layer farms across Indonesia. Antimicrobial resistance represented a significant global threat to both human and animal health, leading to treatment failures, rising healthcare costs, and the spread of resistant pathogens through the food chain. Bacterial resistance mechanisms, including antibiotic inactivation, modifications of antimicrobial target sites, and reduced cellular permeability, particularly in Gram-negative bacteria further exacerbated AMR problem. Globally, regulations on antibiotic use in livestock farming differed significantly, with some countries implementing stringent bans while others continued to permit their use. In Indonesia, the use of antibiotics as growth promoters has been officially prohibited; however, enforcement remained inconsistent due to limited access to veterinary services, inadequate monitoring systems, and insufficient awareness among farmers. Effective AMR management depended on a one health framework that integrates human, animal, and environmental health. To promote responsible antimicrobial use and strengthen veterinary services, cross-sectoral coordination was vital for advancing training, infrastructure, and diagnostics. These efforts enabled the development of evidence-based policies, including regulations on the use of antibiotics in livestock and national action plans supported by robust surveillance systems. By adopting systemic approaches and innovative farm management practices, the risks associated with AMR can be effectively mitigated, ensuring the sustainability of the livestock sector and safeguarding global health.

Keywords: Antibiotic residue, Antibiotic use, Antimicrobial resistance, Layer farming, One health

INTRODUCTION

Indonesia has a large and diverse livestock population, with layer chickens among the most prominent livestock species. As demand for eggs continues to increase, farming practices have become more intensive and increasingly rely on antibiotics to maintain productivity and control disease (BPPSDMP, 2025). Furthermore, this phenomenon has been observed in Southeast Asia, including Indonesia. Antimicrobial medicines are highly effective in treating infectious diseases caused by pathogenic bacteria, which often adversely affect egg production (Wall, 2019). However, the escalating use of antimicrobials for disease prevention and treatment, driven by the need to maintain high egg production levels, is a major contributor to the emergence and spread of antimicrobial resistance (AMR; Salam et al., 2023). Antimicrobial resistance represented a persistent and critical global health challenge, with profound negative implications for both human and animal health (Gray et al., 2021). The intensive farming model, in response to rising egg demand, exerted strong selective pressure, facilitating the emergence and spread of resistant bacteria from farms to humans through the food chain, the environment, and direct contact, ultimately causing treatment failures. If AMR is not properly managed, it could cause more than 10 million deaths per year by 2050 (de Kraker et al., 2016). Raising awareness among layer farmers about AMR is essential to mitigating this global issue. However, studies indicated that many farmers lack a

To cite this paper: Mahapurta IM, Agustina KK, and Besung INK (2026). Development of Antimicrobial Resistance in Layer Chicken Farms in Indonesia: A Review. *J. World Poult. Res.*, 16(1): 110-126. DOI: https://dx.doi.org/10.36380/jwpr.2026.12

comprehensive understanding of AMR and the factors that contribute to its development (Mudenda et al., 2022). Addressing this knowledge gap is critical to implementing effective strategies to reduce antimicrobial misuse and combat the spread of bacterial resistance (Salam et al., 2023).

Many poultry farmers in lower- to middle-income countries, such as Indonesia, have unrestricted access to antibiotics without a veterinary prescription (Coyne et al., 2020; BPPSDMP, 2025). This unrestricted access facilitated the purchase and administration of antibiotics to poultry without veterinary professional oversight. Consequently, farmers often fail to adhere to recommended antibiotic dosages or comply with required withdrawal periods before marketing poultry products (Manyi-Loh et al., 2018). Scientific evidence demonstrated a direct correlation between antibiotic consumption and the development of AMR (Medic et al., 2023). This highlighted that inappropriate use of antimicrobials, including excessive and improper use, plays a central role in the development and dissemination of AMR (Salam et al., 2023). Furthermore, antimicrobials have been widely misused in poultry production systems, including their incorporation into poultry feed and drinking water. These practices commonly focus on promoting growth, increasing egg production, preventing disease (prophylaxis), and providing empirical treatment when a definitive diagnosis is unavailable (Abreu et al., 2023). The inappropriate use of antimicrobials significantly increases the risk of AMR development in poultry flocks and their associated products, posing a serious threat to both animal and public health (Abreu et al., 2023; Azizi et al., 2024).

Humans can be exposed to antimicrobial-resistant microorganisms from animals through contaminated food (Almansour et al., 2023). Conversely, humans can act as vectors, transmitting these resistant microorganisms back to animals and the surrounding environment (Graham et al., 2019). Currently, numerous microorganisms have developed resistance to antimicrobials that are widely used in the livestock industry (Manyi-Loh et al., 2018). *Escherichia coli* (*E. coli*) is a prominent pathogen that has exhibited high levels of AMR in livestock settings (Lv et al., 2024). Additionally, other antimicrobial-resistant microorganisms, such as *Enterococcus* spp. and *Salmonella* spp., have been frequently identified in livestock production systems (Abreu et al., 2023). Moreover, species such as *Staphylococcus aureus* (*S. aureus*) and *Listeria* spp. have demonstrated resistance to antimicrobials commonly used in poultry and human medicines (Ayoub et al., 2025). The transmission of resistant microorganisms to humans via the food chain poses a significant public health threat, leading to infections that are challenging to treat (Uddin et al., 2021).

In response, many countries have implemented regulations to reduce antibiotic use in livestock (Lindmeier, 2017). Antibiotic growth promoters (AGPs) were first introduced in 1951 when the U.S. Food and Drug Administration approved their use without requiring a veterinary prescription (Ma et al., 2021). A worldwide regulatory change started when Sweden banned AGPs in 1986. This policy was further expanded by the European Union's comprehensive ban in 2006, thereby motivating countries such as Mexico, New Zealand, and South Korea to adopt similar measures (McEwen et al., 2018). In Indonesia, a similar policy was established in 2018 under the minister of agriculture regulation, which regulated the classification and usage of veterinary medicines (Ministry of Agriculture, 2017). The responsible use of antibiotics is critical for ensuring animal welfare and reducing the risk of zoonotic disease transmission to humans (Sattar et al., 2023).

Limited global awareness of AMR among poultry farmers is a key driver of resistance issue, leading to the nonprescription purchase and misuse of antimicrobials and neglect of biosecurity (Kramer et al., 2017; Hassan et al., 2021). Additionally, in Africa, farmers often obtain antibiotics from unregulated suppliers for growth promotion and disease prevention, which exacerbates AMR (Mudenda et al., 2022).

Numerous studies have highlighted the bacterial resistance issue, supporting the implementation of a one health approach to address AMR effectively worldwide (Rousham et al., 2018). The present study aimed to evaluate the effects of antibiotic use in layer farming, assess the potential for AMR development, and explore its implications for animal, human, and environmental health, thereby informing strategies to mitigate AMR and promote sustainable practices in Indonesian layer chicken farms.

MATERIALS AND METHODS

The data for the present study were collected through a comprehensive literature review of scientific articles. The literature search was conducted over a ten-year period from 2015 to 2025. However, only studies reporting bacterial AMR in layer chickens and published in the past five years (2020-2025) were included in the analysis. Investigations were performed using major academic databases, including Google Scholar, Research Gate, ScienceDirect, PubMed, Web of Science, Scopus, and NCBI. The search strategy employed specific keywords, including antibiotic use in layer chicken farms, awareness of AMR and associated factors among layer farmers in Indonesia, and AMR as a one health issue in layer chickens. These keywords were selected to ensure the retrieval of relevant studies addressing antibiotic use, AMR, and related factors within the layer poultry production system.

LAYER FARMING INTENSIFICATION AND ANTIMICROBIAL RESISTANCE DYNAMICS

The global intensification of layer farming, driven by a rising demand for animal protein, has significant implications for antimicrobial use (AMU) and the development of AMR. Intensive, high-density poultry production systems increase the risk of disease stressors, leading farmers to depend on antibiotics for prevention and treatment. This reliance created selective pressure for resistant bacteria (Grzinic et al., 2023; Horvat and Kovacevic, 2025). This strong link between AMU in livestock and the emergence of AMR poses a critical public health challenge, as resistance originating in farms can spread to clinical settings (Bist et al., 2024). The situation is particularly critical in resource-limited regions adopting intensive practices, underscoring a global risk that requires immediate evaluation of AMR trends associated with poultry production (Hedman et al., 2020).

In Indonesia, where egg production and consumption were steadily increasing, this dynamic was particularly evident. From 2017 to 2022, national egg production grew at an annual rate of 3.80%, with East Java accounting for 27.80% of total output. At the same time, per capita egg consumption increased from 17.69 kg to 20.02 kg annually and was expected to keep growing (BPS, 2024). This growing poultry sector is vital to national food security and heightens AMR risks. Therefore, the Indonesian government has created a regulatory framework via the National Action Plan for Antimicrobial Resistance Control (2020-2024) to encourage prudent AMU and reduce the spread of resistance in the food production system.

MECHANISMS OF DISSEMINATION AND EVOLUTION OF ANTIMICROBIAL RESISTANCE

Numerous antibiotics are derived from natural compounds used by microbes to combat one another. Since these chemicals naturally exist in environments like soil, bacteria have had enough time to develop resistance. Consequently, many bacteria in the environment are already resistant to current medicines. This includes intrinsic resistance, a permanent, inherited characteristic that renders an entire bacterial species unaffected by a specific medicine, such as *E. coli,* which is resistant to macrolide antibiotics (Reygaert, 2018). Historically, bacteria have always found ways to resist new antibiotics. This pattern has followed the release of almost every antimicrobial medicine. While the development of antibiotics typically requires at least 10 years before they are approved for general use, bacteria can develop resistance mechanisms within hours, creating a highly unbalanced evolutionary race (Uddin et al., 2021; Muteeb et al., 2023). Acquired bacterial resistance is driven through four primary mechanisms, including antibiotic inactivation, target modification, reduced permeability, and increased efflux (Banin et al., 2017). One major resistance mechanism involves modifications of antimicrobial target sites, most commonly resulting from spontaneous genetic mutations selected under antibiotic pressure. For instance, mutations in genes encoding RNA polymerase and DNA gyrase led to resistance against rifamycins and quinolones, respectively (Belay et al., 2024). Another mechanism entails the enzymatic inactivation or chemical modification of antimicrobial agents, whereby bacterial enzymes neutralize the medicine's efficacy; this process is frequently implicated in resistance to aminoglycosides, chloramphenicol, and β-lactam antibiotics (Singh and Kim, 2025). A third mechanism is reduced cellular permeability, particularly in Gram-negative bacteria, which limits antibiotic entry by restricting transmembrane transport across the cell envelope. The fourth mechanism involves efflux systems that actively expel antibiotics and other toxic compounds from bacterial cells. Collectively, these mechanisms allow bacteria to persist and multiply despite exposure to antimicrobial agents (Peterson and Kaur, 2018; Reygaert, 2018).

CHALLENGES AND MANAGEMENT OF ANTIMICROBIAL USE IN LAYER FARMING

Bacterial diseases, including salmonellosis, colibacillosis, mycoplasmosis, and necrotic enteritis, constitute major health constraints in layer chicken production systems. From 2002 to 2018, these infections consistently ranked among the most commonly documented diseases affecting the layer industry (Redweik et al., 2020). Some farmers employed antimicrobials to improve growth efficiency and feed conversion rates (Miyakawa et al., 2024). Although antimicrobials play an important role in reducing disease incidence and mortality in poultry, their inappropriate use poses serious risks to public health. Antimicrobial resistance leads to prolonged illness, increased medical expenditures, and the spread of drug-resistant pathogens within healthcare settings, thereby imposing considerable economic pressures on individuals and families (Dadgostar, 2019).

In Indonesia, evidence of AMR in poultry production systems has been increasingly documented. Studies have reported high levels of antibiotic resistance among *E. coli* and *Salmonella* spp. isolated from chickens and chicken products (Ramdani et al., 2024; Wibisono et al., 2025). *Escherichia coli* isolates from chicken meat in East Java, Indonesia, demonstrated resistance rates of 75% to amoxicillin and ampicillin and 59% to oxytetracycline, while *Salmonella* spp. exhibited 84% resistance to oxytetracycline, with multidrug resistance detected in 42–43% of isolates, indicating widespread resistant bacteria in the poultry food chain (Gresik District, East Java; Wibisono et al., 2025). Additionally, *E. coli* from cloacal swabs of layer chickens in Indonesia exhibited high resistance to quinolone antibiotics, including ciprofloxacin (45%) and enrofloxacin (44.7%), with 44.4% of isolates classified as multidrug-resistant, highlighting significant AMR challenges within layer farms (Hidayah et al., 2024).

The majority of layer farmers utilized antimicrobials primarily for prophylactic purposes, often in response to inadequate farm management, to prevent common diseases, or due to a lack of vaccination programs (Kisoo et al., 2023). Furthermore, the high cost of veterinary services drove farmers to rely on antimicrobials as a preventive measure against severe diseases (Dadgostar, 2019). Consequently, farmers often rely on their personal experience or subjective perceptions of disease risk when administering antimicrobials, often without proper diagnostic confirmation (Toghroli et al., 2024). Additionally, the use of antimicrobials in layer farming is heavily influenced by recommendations from suppliers, such as feed vendors and day-old chicken providers, who often collaborate with pharmaceutical companies to achieve sales targets. This dynamic greatly influenced farmers' decisions to use antimicrobials, thereby prolonging this cycle. In Indonesia, livestock producers frequently rely on external technical advice and supplied inputs when deciding which antibiotics to use, and many farmers obtain antimicrobial products through non-veterinary channels with limited professional oversight, contributing to the widespread and routine use of antibiotics in poultry production. Surveys in major poultry-producing regions such as West Java, East Java, and South Sulawesi, Indonesia, found that over 80% of farmers regularly used antibiotics to prevent disease, and a substantial portion used antibiotics for treatment, despite the national policies prohibiting the use of AGPs since 2018 (FAO, 2018). Furthermore, since poultry accounts for the majority of AMU in livestock, choices made by suppliers and integrators significantly influence overall usage trends. These practices not only influenced on-farm antibiotic use but also contributed to the high levels of AMU observed in Indonesian poultry production, reinforcing dependence on these medicines (Imam et al., 2020; KSI, 2025).

RISKS AND REGULATIONS OF ANTIMICROBIAL USE IN LAYER FARMING

The affordability and efficacy of antibiotics have led to their widespread use (Rodrigues et al., 2022). The European Union adopted similar regulations but later banned 25 types of AGPs in 2006. Other countries, such as Mexico, South Korea, and New Zealand, have implemented bans on AGP use, while nations such as Japan and several non-OECD countries, including China, Brazil, and India, have continued to permit their use (Krysiak et al., 2021). In Indonesia, the use of AGPs was prohibited in 2018 under the Minister of Agriculture Regulation (Widyatmanti et al., 2022). Despite the ban on AGPs, antibiotics remain essential for preventing and treating bacterial infections, supporting animal welfare, and mitigating the risk of zoonotic diseases (Sattar et al., 2023).

The widespread use of antibiotics in animal farming for growth promotion, disease prevention, and treatment, despite ongoing global regulatory gaps for AGPs, has directly promoted the development and emergence of AMR, even though regions such as the European Union have implemented bans (Hedman et al., 2020). The economic impact of banning AGPs was relatively limited in countries with advanced production systems but was substantial in low-income countries where poor sanitation and biosecurity measures are common (Coyne et al., 2020). Certain antibiotics, including tetracyclines, aminoglycosides, and β-lactams, remain critical for maintaining animal health (Matheou et al., 2025). Consequently, a careful and logical evaluation of antibiotic use in layer farming is essential to strike a balance between the demands of animal production and the global imperative to manage AMR effectively (Abreu et al., 2023).

ANTIBIOTIC RESIDUES FOUND IN EGGS IN INDONESIA

Several studies in Indonesia have reported the presence of antibiotic residues in eggs available in the market, indicating widespread and insufficiently controlled antibiotic use in layer production systems and underscoring the need for stricter regulatory oversight and enforcement in the livestock sector (BPPSDMP, 2025; Nur et al., 2025). A recent report focused on identifying bacterial contamination and antibiotic residues in animal products such as meat and eggs from Bali, West Nusa Tenggara, and East Nusa Tenggara, Indonesia, in accordance with Indonesian Law No. 7 of 1996. These regulations indicated that animal products should adhere to the standards of being Safe, Healthy, Whole, and Halal. The bacterial targets of the study conducted by Tenaya et al. (2024), namely *E. coli*, *Streptococcus aureus*, *Salmonella* spp., and *Campylobacter* spp., were all of critical importance to public health as common agents of foodborne illness in Bali and Nusa Tenggara of Indonesia (Tenaya et al., 2024). Additionally, in several locations of Indonesia, antibiotic residues, including penicillin, tetracycline, aminoglycosides, and macrolides, were detected in animal product samples, such as eggs, raising concerns about their potential contribution to AMR (Bura et al., 2024). Of 601 poultry product samples collected from Bali and Nusa Tenggara, Indonesia, 213 (35.44%) contained antibiotic residues (Tenaya et al., 2024). All chicken meat, quail egg, and liver samples collected from the study regions contained detectable levels of antibiotic residues, indicating widespread and insufficiently regulated antibiotic use. The distribution of residues showed the highest prevalence for penicillins (13%), followed by aminoglycosides (9%), macrolides (8%), and tetracyclines (5.5%; Tenaya et al., 2024).

Meanwhile, a 2020 study conducted in East Jakarta, Indonesia, focused on detecting antibiotic residues from the aminoglycoside group, specifically kanamycin, and on assessing the microbiological quality of chicken eggs sold in traditional markets and supermarkets. The study analyzed 100 egg samples and found that 27% contained kanamycin residues, indicating substantial consumer exposure to antibiotic residues in commercially available eggs. Furthermore, eggs purchased from traditional markets had higher levels of contamination than those from supermarkets. These findings suggest that non-compliant practices, such as the use of antibiotics without adhering to proper withdrawal periods before egg collection, persist in the poultry industry in Indonesia. Such practices pose potential risks to consumer health and highlight the need for stricter adherence to food safety standards (Anton et al., 2020).

In 2019, a study was conducted to detect antibiotic residues in chicken eggs obtained from both farmers and distributors in Denpasar, Bali, Indonesia (Witoko et al., 2019). A total of 24 egg samples were randomly collected and analyzed using a bioassay. The results showed that 13 out of 18 samples from farmers and 1 out of 6 samples from distributors tested positive for antibiotic residues. Among the positive samples, aminoglycoside residues were the most common, detected in 66.7% of the eggs from farmers. Tetracycline residues were found in 44.4% of the farmers' eggs and 16.7% of the distributors' eggs, while macrolide residues were present in 16.7% of the farmers' eggs. These findings highlight the prevalence of antibiotic residues in eggs and emphasize the need for enhanced monitoring and regulation of antibiotic use in poultry farming (Witoko et al., 2019).

A study conducted in Yogyakarta, Indonesia, in May 2018 found that 100% (24 out of 24) of the tested egg samples contained antibiotic residues, with 75% (18 out of 24) testing positive for penicillin residues, 12.5% (3 out of 24) for aminoglycoside residues, and another 12.5% (3 out of 24) for oxytetracycline residues (Sivalingam, 2019). Similarly, a study in Semarang Regency focusing on tetracycline residues in chicken eggs sourced directly from farms revealed that 3.3% of the tested samples contained tetracycline residues, with an inhibition zone of 27 mm, indicating significant residue levels. Although the proportion of contaminated samples was relatively low, the detected concentrations raised concerns about potential long-term health risks for consumers, particularly with prolonged exposure through regular consumption (Sa’adah, 2017).

Utari et al. (2018) reported the results of antibiotic residue testing conducted at the BPMSPH Laboratory in Bogor, Indonesia (2017). The study revealed that no penicillin residues were detected in chicken egg samples over three consecutive years (2015-2017), indicating controlled usage. In contrast, macrolide residues showed a fluctuating trend, with a positive detection rate of 1.25% in 2015, dropping to 0% in 2016, and slightly increasing to 0.13% in 2017. Similarly, aminoglycoside and tetracycline residues declined significantly, from 46.25% in 2015 to 2.06% in 2016, and then to 0.13% in 2017. These trends suggest improvements in the regulation of antibiotic use within Indonesia’s layer sector, although continued efforts are necessary to ensure food safety and mitigate the risk of

AMR at the national level (Utari et al., 2018). Another study conducted in 2015 analyzed 1,300 egg samples collected from 13 provinces across Indonesia. The results revealed antibiotic residues in the sampled eggs, with 0.77% beta-lactam residues and 0.62% tetracycline residues (Nurhidayah et al., 2015).

ANTIBIOTIC-RESISTANT BACTERIA IN LAYER CHICKEN FARMS IN INDONESIA

Several studies have investigated bacterial resistance in layer farms across Indonesia (Table 1). Table 1 summarizes the antibiotic susceptibility profiles of bacterial isolates recovered from layer chickens in several regions of Indonesia over a five-year period (2020-2024). The majority of studies focused on *E. coli*, although other clinically relevant pathogens, including *Salmonella* spp., *S. aureus*, *Pasteurella multocida*, *Proteus* spp., and *Klebsiella pneumoniae*, were reported. The recent findings demonstrated substantial heterogeneity in resistance patterns across bacterial species, geographic locations, and antibiotic classes. These findings indicated widespread and persistent AMR among bacterial pathogens isolated from layer chickens in Indonesia. The frequent detection of resistance to critical antimicrobials highlighted the urgent need for improved antimicrobial stewardship, biosecurity, and surveillance in poultry to prevent AMR transmission to humans' environment.

Table 1. Reports on antibiotic resistance in bacterial isolates from layer chickens in Indonesia, from 2020-2024.

Location	Microbes	Number of samples	Antibiotic class	Antibiotic	Percentage (%)			Source
					S	I	R	
Blitar, East Java	*E. coli*	34	Cephalosporin	Cephazolin	97	0	3	Witaningrum et al. (2020)
				Ceftazidime	94	0	6	
				Cefepime	94	0	6	
			Beta lactam	Amoxiclav	100	0	0	
				Ampicillin Sulbactam	100	0	0	
				Ampicillin	38	0	62	
				Meropenem	100	0	0	
			Aminoglycosides	Gentamycin	82	0	18	
				Amikacin	100	0	0	
			Tetracycline	Tetracycline	32	15	53	
			Quinolone	Ciprofloxacin	35	9	56	
				Levofloxacin	47	18	35	
			Amphenicol	Chloramphenicol	97	0	3	
			Sulfonamida and combination	Trimethrophim-sulfamethoxazole	47	0	53	
Tabanan, Bali	*E. coli*	44 samples, less than seven-day-old chickens	Cyclic polypeptide	Bacitracin	93.02	2.33	4.65	Besung et al. (2024)
			Tetracycline	Oxytetracycline	90.7	9.3	0	
			Linkosamida	Clindamycin	95.35	0	4.65	
			Sulfonamida and combination	Trimethrophim-sulfamethoxazole	69.77	0	30.23	
			Aminoglycosides	Streptomycin	88.37	0	11.63	
				Kanamycin	34.88	2.33	62.79	
			Beta lactam	Ampicillin	90.7	0	9.3	
			Quinolone	Enrofloxacin	46.51	16.28	37.21	
		41 samples, 8-	Cyclic polypeptide	Bacitracin	97.56	2.44	0	

		30-day-old chickens	Tetracycline	Oxytetracycline	95.12	4.88	0	
			Linkosamida	Clindamycin	97.56	0	2.44	
			Sulfonamida and combination	Trimethrophim-sulfamethoxazole	70.73	0	29.27	
			Aminoglycosides	Streptomycin	29.27	26.83	43.9	
				Kanamycin	14.63	0	85.37	
			Beta lactam	Ampicillin	75.61	0	24.39	
			Quinolone	Enrofloxacin	85.37	0	14.63	
		49 samples, over 30- day-old chickens	Cyclic polypeptide	Bacitracin	100	0	0	
			Tetracycline	Oxytetracycline	100	0	0	
			Linkosamida	Clindamycin	100	0	0	
			Sulfonamida and combination	Trimethrophim-sulfamethoxazole	14.29	0	85.71	
			Aminoglycosides	Streptomycin	48.98	10.2	40.82	
				Kanamycin	18.37	0	81.63	
			Beta lactam	Ampicillin	18.37	20.41	61.22	
			Quinolone	Enrofloxacin	12.24	30.61	57.15	
Tabanan, Bali	*E. coli*	12	Sulfonamida and combination	Trimethrophim-sulfamethoxazole	100	0	0	Ashley et al. (2024)
			Aminoglycosides	Kanamycin	50	0	50	
			Quinolone	Enrofloxacin	83	17	0	
Jember, East java	*E. coli*	4	Macrolide	Azithromycin	50	0	50	Suswati et al. (2023)
			Sulfonamida	Sulfametoxazole	0	0	100	
			Quinolone	Ciprofloxacin	0	0	100	
			Cephalosporin	Cefixime	0	0	100	
				Ceftriaxone	0	0	100	
			Beta lactam	Amoxiclav	0	0	100	
			Tetracycline	Tetracycline	0	0	100	
			Amphenicol	Chloramphenicol	0	0	100	
Medan, North Sumatera	*E. coli*	7	Beta lactam	Ampicillin	0	0	100	Audiya et al. (2023)
			Tetracycline	Tetracycline	29	0	71	
			Quinolone	Ciprofloxacin	60	26	14	
			Amphenicol	Chloramphenicol	100	0	0	
			Aminoglycosides	Gentamycin	76	24	0	
Blitar, East Java	*E. coli*	27	Beta lactam	Ampicillin	22.2	0	77.8	Wibisono et al. (2020)
			Aminoglycosides	Streptomycin	18.5	14.3	66.7	
			Macrolide	Erythromycin	0	3.7	96.3	
			Tetracycline	Tetracycline	40.7	14.8	44.4	
			Sulfonamida and combination	Trimethrophim-sulfamethoxazole	40.7	0	59.3	
Sesaot, West Lombok	*Salmonella sp.*	8	Beta lactam	Penicillin	25	0	75	April et al. (2022)
			Tetracycline	Oxytetracycline	12.5	12.5	75	
				Tetracycline	12.5	50	37.5	

Kediri, West Lombok	*Salmonella sp.*	10	Beta lactam	Aztreonam	90	10	0	Ramdani et al. (2024)
			Tetracycline	Tetracycline	10	40	50	
			Aminoglycosides	Streptomicin	40	10	50	
			Amphenicol	Chloramphenicol	100	0	0	
			Quinolone	Ciprofloxacin	10	80	10	
Bogor, West Java	*Staphylococcus aureus*	15	Tetracycline	Tetracycline	0	0	100	Hermana et al. (2021)
				Oxytetracycline	0	0	100	
			Beta lactam	Ampicillin	0	0	100	
			Aminoglycosides	Gentamycin	100	0	0	
			Quinolone	Nalidixic acid	0	0	100	
				Enrofloxacin	27	0	73	
				Ciprofloxacin	27	33	40	
			Macrolide	Erythromycin	0	0	100	
			Amphenicol	Chloramphenicol	87	0	13	
West Java	*Pasteurella multocida*	9	Beta lactam	Amoxicillin	66.7	0	33.3	Sunartatie et al. (2024)
			Tetracycline	Tetracycline	88.9	0	11.1	
			Quinolone	Ciprofloxacin	66.7	0	33.3	
				Enrofloxacin	88.9	0	11.1	
			Polymyxins	Colistin	0	0	100	
			Sulfonamida	Sulfamethoxazole	100	0	0	
			Linkosamida	Lincomycin	88.9	0	11.1	
Jember, East java	*Proteus spp*	3	Macrolide	Azithromycin	66.7	0	33.3	Suswati et al. (2023)
			Sulfonamida	Sulfametoxazole	0	0	100	
			Quinolone	Ciprofloxacin	0	0	100	
			Cephalosporin	Cefixime	0	0	100	
				Ceftriaxone	0	0	100	
			Beta lactam	Amoxiclav	0	0	100	
			Tetracycline	Tetracycline	0	0	100	
			Amphenicol	Chloramphenicol	0	0	100	
Blitar, East Java	*Klebsiella pneumoniae*	6	Beta lactam	Ampicillin	33.3	0	66.7	Permatasari et al. (2020)
			Aminoglycosides	Streptomycin	66.7	0	33.3	
			Macrolide	Erythromycin	0	50	50	
			Tetracycline	Tetracycline	50	0	50	
			Sulfonamida	Sulfametoxazole	50	0	50	

S: Sensitive; I: Intermediate; R: Resistant

Among *E. coli* isolates, high levels of resistance were consistently observed against commonly used antibiotics, particularly tetracyclines, sulfonamides, quinolones, and β-lactams (Niasono et al., 2019). In Blitar, East Java, Indonesia, *E. coli* isolates exhibited high resistance rates of 62-77.8% to ampicillin, 44.4-53% to tetracycline, 56% to ciprofloxacin, and 53-59.3% to trimethoprim–sulfamethoxazole, suggesting multidrug resistance. Similar trends were observed in Medan, North Sumatra, Indonesia, where *E. coli* isolates demonstrated high resistance to tetracycline (71%) and complete resistance to ampicillin (100%). In contrast, susceptibility to carbapenems (meropenem) and certain aminoglycosides (amikacin) remained high in several locations (Wibisono et al., 2020; Audiya et al., 2023; Suswati et al., 2023; Ashley et al., 2024).

Age-related differences in resistance profiles were evident in *E. coli* isolates from Tabanan, Bali, Indonesia. Isolates from younger chickens (less than seven days old) indicated relatively high susceptibility to oxytetracycline, ampicillin, and bacitracin, whereas increased resistance to kanamycin, enrofloxacin, and trimethoprim–sulfamethoxazole was observed in older age groups (older than 30 days old). Notably, resistance to sulfonamides and aminoglycosides increased markedly with age, suggesting the cumulative exposure to antimicrobial agents during the production cycle (Besung et al., 2024).

Extremely high resistance levels were reported in small sample studies from Jember, East Java, Indonesia, where *E. coli* and *Proteus* spp. isolates exhibited 100% resistance to multiple antibiotic classes, including quinolones, cephalosporins, tetracyclines, β-lactams, and amphenicols. Although the sample sizes were limited, these findings highlighted the potential presence of extensively drug-resistant strains in poultry production systems (Suswati et al., 2023; 2025).

Non-*E. coli* pathogens also demonstrated concerning resistance patterns. *Salmonella* spp. isolates from West Lombok and Kediri, Indonesia, exhibited high resistance to tetracyclines (50-75%) and β-lactams (up to 75%), while maintaining susceptibility to chloramphenicol in some studies. *Staphylococcus aureus* isolates from Bogor, West Java, Indonesia, were uniformly resistant (100%) to tetracyclines, ampicillin, erythromycin, nalidixic acid, and enrofloxacin, indicating a high burden of multidrug resistance. Similarly, *Pasteurella multocida* isolates were completely resistant to colistin, raising significant public health concerns.

POTENTIAL RISK OF ANTIMICROBIAL RESISTANCE EXPOSURE IN HUMANS ASSOCIATED WITH THE DEVELOPMENT OF LAYER FARMING

The poultry sector faces several threats, including predation and subpar feed quality, structural weaknesses such as inadequate infrastructure and limited financial resources, and systemic gaps in policy, training, and biosecurity that pose serious public health risks (Wong et al., 2017). Intensive poultry farming systems, particularly in resource-limited settings, can worsen existing public health problems. Without appropriate oversight, the growth of layer farming could unintentionally worsen poverty and food insecurity (Boeckel et al., 2019). Many development programs sourced poultry stock from large-scale commercial farms, which increased the risk of exposing households and communities to AMR bacteria and zoonotic diseases (Hedman et al., 2020).

The proximity of layer farms to human residences in resource-limited areas has increased the risk of AMR transmission, driven by insufficient sanitation, substandard hygiene, and frequent human-animal contact (Struik and Kuyper, 2017). Additionally, this proximity increased the likelihood of anthropo-zoonotic transmission, in which resistant *E. coli* from humans spread to animals (Olaru et al., 2023). This can lead to resistance against antibiotics such as fluoroquinolones and colistin, which are rarely used in poultry farming in low- and middle-income countries (Monte et al., 2017).

Live animal markets further contributed to the spread of AMR and infectious diseases in layer farming. In live markets, animals from different geographic locations are sold, creating opportunities for pathogens to cross species barriers and infect humans (Hedman et al., 2020). Poultry sold in these markets often originates from intensive farms with high AMU, resulting in day-old chickens frequently harboring multidrug-resistant bacteria (Okorafor et al., 2019).

A MULTIDISCIPLINARY APPROACH TO TACKLING ANTIMICROBIAL RESISTANCE IN LAYER FARMING

The growing global challenge of AMR has led experts to develop innovative interventions to properly understand and address the complex social and ecological factors that influence the evolution, spread, and persistence of AMR (Salam et al., 2023). Guided by the multidisciplinary principles of Boulding's Skeleton of Science, a framework previously applied to emerging infectious diseases, the present study analyzed AMR in layer farming using a systems-based approach. Specifically, the framework was used to examine AMR as a complex phenomenon shaped by interactions across multiple levels, including microbial dynamics, farm management practices, AMU patterns, and broader human-animal-environment interfaces. By integrating ecological and epidemiological perspectives, this approach enabled a more comprehensive understanding of how AMR emerges, persists, and spreads within layer production systems (Coque et al., 2023).

The AMR determinants significantly influence bacterial resistance patterns in layer farming. It is important to note that the selective pressures leading to resistance are significantly affected by differences in

AMU, such as the types of antimicrobials administered, the duration of treatment, and the defined daily dose (Morrow, 2024). Studying ecological indicator species within poultry microbiota can provide valuable insights into bacterial populations that respond to changes in AMU patterns (Bennani et al., 2020).

While existing studies on poultry AMR have predominantly examined foodborne pathogens such as *E. coli*, *Salmonella*, and *Campylobacter* spp. for their clinical relevance (Shang et al., 2023), the threat posed by commensal bacteria and other opportunistic pathogens is significant. Commensals can act as reservoirs of resistance genes, facilitating their transfer to human pathogens and thereby posing a major public health risk. Monitoring poultry microbiomes and resistomes can provide a more detailed understanding of ecological diversity and host-microbe interactions related to AMR (Kilonzo-Nthenge et al., 2024). The factors leading to resistance to poultry-derived foods, such as eggs, differ by farming methods (Samtiya et al., 2022). Products such as meat and eggs from farms that regularly use antimicrobials are more likely to contain AMR bacteria than products from antimicrobial-free farms. In many developing countries, the need to feed growing cities and the continued use of older farming techniques combined to create a wide gap in antibiotic use (Mottet and Tempio, 2017).

Many international development projects promoted small-scale intensive poultry farming to reduce poverty. However, without adequate biosecurity measures and ongoing financial support, these initiatives can unintentionally raise the risk of zoonotic diseases and AMR, placing additional stress on farming households. (Hedman et al., 2021). The intensification of poultry production may have broader socio-economic impacts, including changes in gender roles in poultry management and shifts in local markets driven by cultural preferences for poultry products such as eggs (Struik and Kuyper, 2017).

Figure 1 illustrates a conceptual pathway explaining how intensive battery cage systems in layer chicken production can contribute to the development of AMR. Prolonged limitations at high stocking density induce chronic physiological stress that suppresses the immune system and increases susceptibility to infectious diseases. Environmental stressors, such as sudden weather changes, further exacerbate health risks and heighten farmers' concern over disease outbreaks and productivity losses (Abo-Al-Ela et al., 2021). Therefore, veterinary medicines, including antibiotics, are frequently used, often empirically or prophylactically, to manage stress-related diseases. Repeated and inappropriate antibiotic exposure creates selective pressure on bacterial populations, enabling the survival and proliferation of resistant strains. These resistant bacteria may subsequently spread within poultry flocks, contaminate the farm environment, and enter the food chain, posing significant risks to animal health, public health, and the broader One Health system (Abo-Al-Ela et al., 2021; Niu et al., 2022; Grzinic et al., 2023).

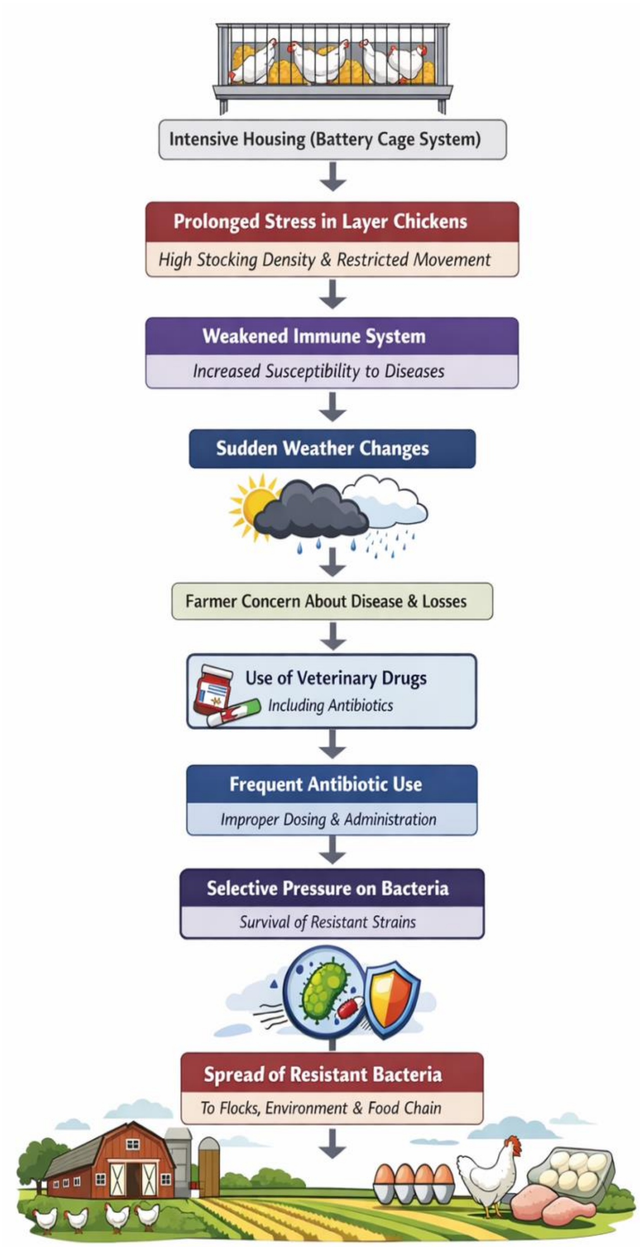

Figure 1. Conceptual pathway linking intensive battery cage systems, antibiotic use, and the emergence of antimicrobial resistance in layer chickens (Figure produced by Canva software)

VETERINARY MANAGEMENT AND THE ONE HEALTH APPROACH TO COMBAT ANTIMICROBIAL RESISTANCE

Effective control of the growing threat of bacterial resistance depends heavily on well-functioning veterinary services. Nevertheless, assessments by the World Organization for Animal Health (WOAH) indicated that, in many countries, these services have not yet met internationally recommended performance levels. This posed significant biosafety risks not only for food production in low- and middle-income countries but also for their international trading counterparts (WOAH, 2024).

International support for veterinary services remains inadequate. Further complicating the matter, profit-driven motives might cause some veterinarians to overprescribe antibiotics. In many countries, particularly low- and middle-income regions such as Indonesia, animal health agendas reflect an incomplete approach to disease management by focusing narrowly on a limited set of pathogens. Furthermore, the lack of comprehensive veterinary education programs in many regions continues to hinder progress (Odoi et al., 2021). Political commitment is often insufficient, with outdated or nonexistent policies regulating AMU. Moreover, post-market surveillance of veterinary antimicrobial products is rare, allowing counterfeit medicines to enter the market and undermine treatment efficacy. Effective, transparent, and well-managed veterinary services are critical to reducing the spread of AMR. Achieving effective AMR control requires an integrated approach that includes education, surveillance, and policy reform (WBG, 2017).

Reducing the risks of AMR linked to AMU in livestock requires an integrated One Health approach that acknowledges the interrelation of human, animal, and environmental health and promotes coordinated efforts among these sectors (Cella et al., 2023). Key components of this strategy include governance, surveillance systems, educational initiatives, investigation, preventive measures, and public awareness campaigns. Additionally, alternatives to antibiotics, such as probiotics, prebiotics, enzymes, and essential oils, were increasingly being explored to reduce reliance on antibiotics in livestock production (Muteeb et al., 2023). Scientific studies from Indonesia demonstrated that probiotics and herbal feed additives can serve as effective alternatives to traditional antibiotics in poultry farming, offering potential benefits for reducing AMR. A recent study demonstrated that supplementing layer hen diets with probiotics such as *Lactobacillus plantarum* can enhance intestinal health, improve immune function, and reduce the load of *E. coli* in the small intestine, indicating the capacity to suppress pathogenic bacterial populations without antibiotic use (Agpretasia et al., 2024). Additionally, experimental studies on herbal probiotic combinations suggested that these probiotics can modulate gut microbial resistance traits and improve host performance. This finding indicated the role of herbal probiotics in promoting a healthier gut microbiome and reducing selection pressure that drives the emergence of AMR (Sabdoningrum et al., 2020). These findings suggested that probiotics and herbal interventions play important roles in a sustainable One Health-based strategy to mitigate AMR in Indonesia. (Dharmayanti et al., 2025).

In layer farming, the One Health approach is particularly vital for combating AMR, as it integrates surveillance, policy development, and investigations to address antibiotic overuse. The One Health approach promotes sustainable practices, improves biosecurity, and educates farmers, which helps prevent resistant bacteria from spreading to humans and the environment. Additionally, this approach ensures safer food production and protects public health (Zhang et al., 2024). Ultimately, the one health strategy can provide a comprehensive framework for tackling AMR through coordinated, proactive interventions.

CONCLUSION

The present findings demonstrated that AMR among bacterial isolates from layer chickens in Indonesia is widespread, multifaceted, and geographically diverse. High levels of resistance were consistently observed across major bacterial pathogens, particularly *E. coli*, *Salmonella* spp., *S. aureus*, and other opportunistic organisms, against commonly used antibiotic classes such as β-lactams, tetracyclines, sulfonamides, quinolones, and, in some cases, critically important antimicrobials. These resistance patterns strongly reflected the intensive and often inappropriate use of antibiotics in layer farming for therapeutic, prophylactic, and growth-promotion purposes. During disease outbreaks, high levels of AMU exerted selective pressure, allowing resistant strains to proliferate and survive in poultry populations and on farms, including in manure, drinking water, and feed.

The current study indicated that poor biosecurity, inaccurate diagnoses and prescription-based treatments, lack of antibiotic rotation, and mixing chickens of different ages or sources significantly promoted the growth and spread of resistant bacteria. The persistence of antibiotic residues within poultry farming systems has intensified this selective pressure, thereby expediting the emergence of resistant strains and promoting horizontal gene transfer among bacterial populations. These conditions had severe impacts on poultry health and productivity, leading to greater economic losses from decreased egg production and rising treatment costs. Additionally, significant public health risks were associated with increasing the spread of resistant bacteria through eggs, poultry products, and environmental pathways.

Future studies should focus on longitudinal and farm-level investigations to clarify how antibiotic use influences AMR development and resistance patterns in layer farms. Molecular characterization of resistance genes, including plasmid-mediated and mobile genetic elements, is essential for understanding their transmission within farms, between farms, and across the human-animal-environment interface. Additionally, integrated One Health approaches linking poultry-derived AMR to human clinical isolates and environmental reservoirs would provide critical evidence for risk assessment. Assessments of alternative disease management strategies, including enhanced biosecurity, vaccination, probiotics, and antimicrobial stewardship, are crucial for guiding evidence-based policies and supporting sustainable layer farming in Indonesia.

DECLARATIONS

Availability of data and materials

The data supporting the findings of the present study are available from the corresponding author upon reasonable request.

Funding

This study was funded by the Research Budget of Udayana University for the Fiscal Year 2024 under Contract No. B/255.76/UN14.4.A/PT.01.03/2024.

Acknowledgments

The authors would like to express their sincere gratitude to the Master's Program in Veterinary Medicine, Faculty of Veterinary Medicine, Udayana University, for facilitating the implementation of the research and supporting the preparation of this manuscript.

Authors' contribution

I Made Mahaputera conducted data collection, performed data analysis, and prepared the initial manuscript draft. I Nengah Kerta Besung was responsible for study design, data analysis, and manuscript writing. Kadek Karang Agustina contributed to the study design, conducted the scientific literature search, and participated in manuscript writing. All authors read and approved the final edition of the manuscript.

Competing interests

The authors declared that there are no conflicts of interest regarding the data, interpretation, or ownership of this manuscript.

Ethical considerations

All data and information used were obtained from publicly available scientific publications, such as journals, books, and academic articles. The authors ensured academic integrity by properly citing all references and avoiding plagiarism, thereby upholding the principles of academic ethics. Grammarly software was used exclusively for language editing and grammar checking, and then the manuscript was reviewed and revised by the authors before submission. The authors also take full responsibility for using AI for language editing, grammar checking. The figure was created by Deepseek software.

REFERENCES

Abo-Al-Ela HG, El-Kassas S, El-Naggar K, Abdo SE, Jahejo AR, and Wakeel RA (2021). Stress and immunity in poultry: Light management and nanotechnology as effective immune enhancers to fight stress. Cell Stress and Chaperones, 26(3): 457-472. DOI: https://www.doi.org/10.1007/s12192-021-01204-6

Abreu R, Semedo-Lemsaddek T, Cunha E, Tavares L, and Oliveira M (2023). Antimicrobial drug resistance in poultry production: Current status and innovative strategies for bacterial control. Microorganisms, 11(4): 953. DOI: https://www.doi.org/10.3390/microorganisms11040953

Agpretasia Y, Ulupi N, and Arief II (2024). The role of probiotik *Lactobacillus plantarumIIA-1A5* in improving body resistance, performance, and eqq quality of commercial chickens. Jurnal Ilmu Pertanian Indonesia, 29(2): 207-213. DOI: https://www.doi.org/10.18343/jipi.29.2.207

Almansour AM, Alhadlaq MA, Alzahrani KO, Mukhtar LE, Alharbi AL, and Alajel SM (2023). The silent threat: Antimicrobial-resistant pathogens in food-producing animals and their impact on public health. Microorganisms, 11(9): 2127. DOI: https://www.doi.org/10.3390/microorganisms11092127

Anton, Taufik E, and Wulandari Z (2020). Study of antibiotic residues and microbiological quality of consumption chicken eggs circulating in the East Jakarta administrative city. Jurnal Ilmu Produksi Dan Teknologi Hasil Peternakan, 8(3): 151-159. DOI:

https://www.doi.org/10.29244/jipthp.8.3.151-159

April BR, Agustin ALD, Atma CD, and Tirtasari K (2022). Detection of antibiotic resistance *Salmonella sp.* isolated from layer chicken farm in Sesaot West Lombok. Media Kedokteran Hewan, 33(1): 18-25. DOI: https://www.doi.org/10.20473/mkh.v33i1.2022.18-25

Ashley, Besung INK, and Suarjana IGK (2024). Sensitivity of *Escherichia coli* bacteria against antibiotic Trimethoprim-Sulfamethoxazole, Kanamysin, and Enrofloxacin on layer chicken from chicken farm in Penebel, Tabanan, Bali. Buletin Veteriner Udayana, 16(2): 388-396. DOI: https://www.doi.org/10.24843/bulvet.2024.v16.i02.p08

Audiya TS, Dewi RR, Kejora E, and Sihombing JM (2023). Antibiotic resistance of *Escherichia coli* isolated from poultry product. JurnalPeternakan Unggul, 6(2): 44-56. DOI: https://www.doi.org/10.36490/jpu.v6i1.957

Ayoub H, Kumar MS, Dubal ZB, Bhilegaonkar KN, Nguyen-Viet H, Grace D, and Deka RP (2025). Systematic review and meta-analysis on prevalence and antimicrobial resistance patterns of important foodborne pathogens isolated from retail chicken meat and associated environments in India. Foods, 14(4): 555. DOI: https://www.doi.org/10.3390/foods14040555

Azizi MN, Zahir A, Mahaq O, and Aminullah N (2024). The alternatives of antibiotics in poultry production for reducing antimicrobial resistance. World's Veterinary Journal, 14(2): 270-283. DOI: https://www.doi.org/10.54203/scil.2024.wvj34

Badan penyuluhan dan pengembangan SDM pertanian (BPPSDMP) (2025). Antimicrobial resistance and the overuse of antibiotics in animal husbandry in Indonesia. Badan penyuluhan dan pengembangan SDM pertanian [Agricultural extension and human resource development agency]. Ministry of Agriculture, Indonesia. Available at: https://bbpkhcinagara.bppsdmp.pertanian.go.id/artikel/

Badan pusat statistik (BPS) (2024). Production of laying hen eggs by Province (Tons), 2021-2023. Badan Pusat Statistik, Indonesia. Available at: https://www.bps.go.id/id/statistics-table/3/

Banin E, Hughes D, and Kuipers OP (2017). Editorial: Bacterial pathogens, antibiotics and antibiotic resistance. FEMS Microbiology Reviews, 41(3): 450-452. DOI: https://www.doi.org/10.1093/femsre/fux016

Belay WY, Getachew M, Tegegne BA, Teffera ZH, Dagne A, Zeleke TK, and Aschale Y (2024). Mechanism of antibacterial resistance, strategies and next-generation antimicrobials to contain antimicrobial resistance: A review. Frontiers in Pharmacology, 15: 1444781. DOI: https://www.doi.org/10.3389/fphar.2024.1444781

Bennani H, Mateus A, Mays N, Eastmure E, Stärk KDC, and Häsler B (2020). Overview of evidence of antimicrobial use and antimicrobial resistance in the food chain. Antibiotics, 9(2): 49. DOI: https://www.doi.org/10.3390/antibiotics9020049

Besung INK, Sudipa PH, Suarjana IGK, and Suwiti NK (2024). Antibiotic resistance pattern of *Escherichia coli* isolated from layer chicken in Bali-Indonesia. Journal of World's Poultry Research, 14(4): 361-368. DOI: https://www.doi.org/10.36380/jwpr.2024.37

Bist RB, Bist K, Poudel S, Subedi D, Yang X, Paneru B, and Chai L (2024). Sustainable poultry farming practices: A critical review of current strategies and future prospects. Poultry Science, 103(12): 104295. DOI: https://www.doi.org/10.1016/j.psj.2024.104295

Boeckel TPV, Pires J, Silvester R, Zhao C, Song J, Criscuolo NG, and Laxminarayan R (2019). Global trends in antimicrobial resistance in animals in low- And middle-income countries. Science, 365(6459): eaaw1944. DOI: https://www.doi.org/10.1126/science.aaw1944

Bura MAYD, Effendi MH, Puspitasari Y (2024). Profile of antibiotic residue and antibiotic resistance in broiler chicken meat in Indonesia: Public health importance. Jurnal Kajian Veteriner, 12(1): 61-76. DOI: https://www.doi.org/10.35508/jkv.v12i1.15360

Cella E, Giovanetti M, Benedetti F, Scarpa F, Johnston C, Borsetti A, and Ciccozzi M (2023). Joining forces against antibiotic resistance: The one health solution. Pathogens, 12(9): 1074. DOI: https://www.doi.org/10.3390/pathogens12091074

Coque TM, Cantón R, Pérez-Cobas AE, Fernández-de-Bobadilla MD, and Baquero F (2023). Antimicrobial resistance in the global health network: Known unknowns and challenges for efficient responses in the 21st century. Microorganisms, 11(4): 1050. DOI: https://www.doi.org/10.3390/microorganisms11041050

Coyne L, Patrick I, Arief R, Benigno C, Kalpravidh W, McGrane J, and Rushton J (2020). The costs, benefits and human behaviours for antimicrobial use in small commercial broiler chicken systems in Indonesia. Antibiotics, 9(4): 154. DOI: https://www.doi.org/10.3390/antibiotics9040154

Dadgostar P (2019). Antimicrobial resistance: Implications and costs. Infection and Drug Resistance, 12: 3903-3910. DOI: https://www.doi.org/10.2147/IDR.S234610

de Kraker MEA, Stewardson AJ, and Harbarth S (2016). Will 10 million people die a year due to antimicrobial resistance by 2050?. PLoS Medicine, 13(11): e1002184. DOI: https://www.doi.org/10.1371/journal.pmed.1002184

Dharmayanti NLPI, Kusala MKJ, Nuradji H, and Nurjanah D (2025). Antimicrobial resistance in Indonesia: A comprehensive One Health analysis and strategic roadmap for mitigation. International Journal of One Health, 11(1): 34-53. DOI: https://www.doi.org/10.14202/IJOH.2025.34-53

Food and agriculture organization (FAO) (2018). Survey result: Antibiotic use to prevent disease on chicken farms is still high. Indonesia. Available at: https://www.fao.org/indonesia/news/detail/Survey-result-Antibiotic-use-to-prevent-disease-on-chicken-farms-is-still-high/en#:~:text=%22This%20information%20dissemination%20needs%20to,addition%20to%20contributing%20to%20AMR

Graham DW, Bergeron G, Bourassa MW, Dickson J, Gomes F, Howe A, and Wittum TE (2019). Complexities in understanding antimicrobial resistance across domesticated animal, human, and environmental systems. Annals of the New York Academy of Sciences, 1441(1): 17-30. DOI: https://www.doi.org/10.1111/nyas.14036

Gray P, Jenner R, Norris J, Page S, and Browning G (2021). Antimicrobial prescribing guidelines for poultry. Australian Veterinary Journal, 99(6): 181-235. DOI:

https://www.doi.org/10.1111/avj.13034

Grzinic G, Piotrowicz-Cieslak A, Klimkowicz-Pawlas A, Gorny RL, Lawniczek-Wałczyk A, Piechowicz L, Olkowska E, Potrykus M, Tankiewicz M, Krupka M et al. (2023). Intensive poultry farming: A review of the impact on the environment and human health. Science of the Total Environment, 858(3): 1160014. DOI: https://www.doi.org/10.1016/j.scitotenv.2022.160014

Hassan MM, Kalam MA, Alim MA, Shano S, Nayem MRK, Badsha MR, and Islam A (2021). Knowledge, attitude, and practices on antimicrobial use and antimicrobial resistance among commercial poultry farmers in Bangladesh. Antibiotics, 10(7): 784. DOI: https://www.doi.org/10.3390/antibiotics10070784

Hedman HD, Vasco KA, and Zhang L (2020). A review of antimicrobial resistance in poultry farming within low-resource settings. Animals, 10(8): 1264. DOI: https://www.doi.org/10.3390/ani10081264

Hedman HD, Zhang L, Butt B, Papias P, Trostle JA, and Eisenberg JNS (2021). Chicken dumping: Motivations and perceptions in shifting poultry production practices. One Health, 13: 100296. DOI: https://www.doi.org/10.1016/j.onehlt.2021.100296

Hermana NSP, Afiff U, Safika, Indrawati A, Wibawan IWT, and Pasaribu FH (2021). Antibiotic resistant pattern and resistant gene identification of *Staphylococcus aureus* from chicken farm in Bogor. Jurnal Veteriner, 22(2): 262-270. DOI: https://www.doi.org/10.19087/jveteriner.2021.22.2.262

Hidayah N, Palupi MF, Ariyani NA, Indryana, Jannah AM, Komariyah S, Sari RA, Ambarwati, Rusmiati E, Idrishanty N et al. (2024). Prevalnce and level of cross resistance within quinolones group in *Escherichia coli* from layer chicken cloacal swab. Jurnal Sain Veteriner, 42(3): 368-379. DOI: https://www.doi.org/10.22146/jsv.92045

Horvat O and Kovacevic Z (2025). Human and veterinary medicine collaboration: synergistic approach to address antimicrobial resistance through the lens of planetary health. Antibiotics, 14(1): 38. DOI: https://www.doi.org/10.3390/antibiotics14010038

Imam T, Gibson JS, Foysal M, Das SB, Gupta SD, Fournié G, and Henning J (2020). A cross-sectional study of antimicrobial usage on commercial broiler and layer chicken farms in Bangladesh. Frontiers in Veterinary Science, 7: 576113. DOI: https://www.doi.org/10.3389/fvets.2020.576113

Kilonzo-Nthenge A, Rafiqullah I, Netherland M, Nzomo M, Mafiz A, Nahashon S, and Hasan NA (2024). Comparative metagenomics of microbial communities and resistome in southern farming systems: Implications for antimicrobial stewardship and public health. Frontiers in Microbiology, 15: 1443292. DOI: https://www.doi.org/10.3389/fmicb.2024.1443292

Kisoo L, Muloi DM, Oguta W, Ronoh D, Kirwa L, Akoko J, and Wambua L (2023). Practices and drivers for antibiotic use in cattle production systems in Kenya. One Health, 17: 100646. DOI: https://www.doi.org/10.1016/j.onehlt.2023.100646

Kramer T, Jansen LE, Lipman LJA, Smit LAM, Heederik DJJ, and Dorado-García A (2017). Farmers' knowledge and expectations of antimicrobial use and resistance are strongly related to usage in Dutch livestock sectors. Preventive Veterinary Medicine, 147: 142-148. DOI: https://www.doi.org/10.1016/j.prevetmed.2017.08.023

Krysiak K, Konkol D, and Korczyński M (2021). Review overview of the use of probiotics in poultry production. Animals, 11(6): 1620. DOI: https://www.doi.org/10.3390/ani11061620

Knowledge sourcing intelligence (KSI) (2025). Indonesia animal health market - Strategic insights and forecasts (2025-2030). Available at: https://www.knowledge-sourcing.com/report/indonesia-animal-health-market?utm_source=chatgpt.com

Lindmeier C (2017). Stop using antibiotics in healthy animals to prevent the spread of antibiotic resistance. World health Organization. Available at: https://www.who.int/news/item/07-11-2017-stop-using-antibiotics-in-healthy-animals-to-prevent-the-spread-of-antibiotic-resistance

Lv C, Leng J, Qian M, Sun B, Ye H, Li M, and Zhu Y (2024). Antimicrobial resistance in *Escherichia coli* and *Staphylococcus aureus* at human-animal interfaces on Chongming Island, Shanghai: A One Health perspective. One Health, 19: 100910. DOI: https://www.doi.org/10.1016/j.onehlt.2024.100910

Ma F, Xu S, Tang Z, Li Z, and Zhang L (2021). Use of antimicrobials in food animals and impact of transmission of antimicrobial resistance on humans. Biosafety and Health, 3(1): 32-38. DOI: https://www.doi.org/10.1016/j.bsheal.2020.09.004

Manyi-Loh C, Mamphweli S, Meyer E, and Okoh A (2018). Antibiotic use in agriculture and its consequential resistance in environmental sources: Potential public health implications. Molecules, 23(4): 1-48. DOI: https://www.doi.org/10.3390/molecules23040795

Matheou A, Abousetta A, Pascoe AP, Papakostopoulos D, Charalambous L, Panagi S, and Johnson EO (2025). Antibiotic use in livestock farming: A driver of multidrug resistance?. Microorganisms, 13(4): 779. DOI: https://www.doi.org/10.3390/microorganisms13040779

McEwen SA, Angulo FJ, Collignon PJ, Conly JM (2018) Unintended consequences associated with national-level restrictions on antimicrobial use in food-producing animals. Lancet Planet Health, 2(7): e279-e282. DOI: https://www.doi.org/10.1016/S2542-5196(18)30138-4

Medic D, Bozic CB, and Bajcetic M (2023). Impact of antibiotic consumption on antimicrobial resistance to invasive hospital pathogens. Antibiotics, 12(2): 259. DOI: https://www.doi.org/10.3390/antibiotics12020259

Ministry of Agriculture (2017). Regulation of the Minister of Agriculture Number 14/PERMENTAN/PK.350/5/2017 Concerning the Classification of Veterinary Medicinal Products. Republic of Indonesia. Available at: https://peraturan.bpk.go.id/Details/160953/permentan-no-14permentanpk35052017-tahun-2017

Miyakawa MEF, Casanova NA, and Kogut MH (2024). How did antibiotic growth promoters increase growth and feed efficiency in poultry?. Poultry Science, 103(2): 103278. DOI: https://www.doi.org/10.1016/j.psj.2023.103278

Monte DF, Mem A, Fernandes MR, Cerdeira L, Esposito F, Galvão JA, and Landgraf M (2017). Chicken meat as a reservoir of colistin-resistant *Escherichia coli* strains carrying mcr-1 genes in South America. Antimicrobial Agents and Chemotherapy, 61(5): e02718-16. DOI: https://www.doi.org/10.1128/AAC.02718-16

Morrow CJ (2024). Antimicrobial resistance (AMR): An important one health issue for layer and meat poultry industries worldwide. Poultry Science, 103(7): 103690. DOI: https://www.doi.org/10.1016/j.psj.2024.103690

Mottet A and Tempio G (2017). Global poultry production: Current state and future outlook and challenges. World's Poultry Science Journal, 73(2): 245-256. DOI: https://www.doi.org/10.1017/S0043933917000071

Mudenda S, Malama S, Munyeme M, Hang'ombe BM, Mainda G, Kapona O, and Muma JB (2022). Awareness of antimicrobial resistance and associated factors among layer poultry farmers in Zambia: Implications for surveillance and antimicrobial stewardship programs. Antibiotics, 11(3): 383. DOI: https://www.doi.org/10.3390/antibiotics11030383

Muteeb G, Rehman MT, Shahwan M, and Aatif M (2023). Origin of antibiotics and antibiotic resistance, and their impacts on drug development: A narrative review. Pharmaceuticals, 16(11): 1615. DOI: https://www.doi.org/10.3390/ph16111615

Niasono AB, Latif H, Purnawarman T (2019). Antibiotic resistance to Escherichia coli isolated from broiler farms in Subang district, West Java Province. Jurnal Veteriner, 20(2): 187-195. DOI: https://www.doi.org/10.19087/jveteriner.2019.20.2.187

Niu X, Ding Y, Chen S, Gooneratne R, and Ju X (2022). Effect of immune stress on growth performance and immune functions of livestock: Mechanisms and prevention. Animals, 12(7): 909. DOI: https://www.doi.org/10.3390/ani12070909

Nur AM, Suharto RH, Mursalim MF, and Toputri NAA (2025). Detection of antibiotic residues in chicken eggs from traditional markets in Maros regency using the bioassay method. Jurnal Riset Veteriner Indonesia, 9(2): 16-23. DOI: https://www.doi.org/10.20956/jrvi.v9i2.48664

Nurhidayah, Yulianti NT, Palupi MF, Ariyani N, Patriana U, Werdiningsih S, and Rusmiati E (2015). Assessment of residues of several classes of antibiotics in chicken eggs in several provinces in Indonesia. Buletin Pengujian Mutu Obat Hewan, 23: 1-8. Available at: https://repository.pertanian.go.id/handle/123456789/21376

Odoi A, Samuels R, Carter CN, and Smith J (2021). Antibiotic prescription practices and opinions regarding antimicrobial resistance among veterinarians in Kentucky, USA. PloS One, 16(4): e0249653. DOI: https://www.doi.org/10.1371/journal.pone.0249653

Okorafor ON, Anyanwu MU, Nwafor EO, AnosaGN, and Udegbunam RI (2019). Multidrug-resistant enterobacteria colonize commercial day-old broiler chicks in Nigeria. Veterinary World, 12(3): 418-423. DOI: https://www.doi.org/10.14202/vetworld.2019.418-423

Olaru ID, Walther B, and Schaumburg F (2023). Zoonotic sources and the spread of antimicrobial resistance from the perspective of low and middle-income countries. Infectious Diseases of Poverty, 12: 59. DOI: https://www.doi.org/10.1186/s40249-023-01113-z

Permatasari DA, Witaningrum AM, Wibisono FJ, Effendi MH (2020). Detection and prevalence of multidrug-resistant *Klebsiella pneumoniae* strains isolated from poultry farms in Blitar, Indonesia. Biodiversitas, 21(10): 4642-4647. DOI: https://www.doi.org/10.13057/biodiv/d211024

Peterson E and Kaur P (2018). Antibiotic resistance mechanisms in bacteria: Relationships between resistance determinants of antibiotic producers, environmental bacteria, and clinical pathogens. Frontiers in Microbiology, 9: 2928. DOI: https://www.doi.org/10.3389/fmicb.2018.02928

Ramdani FA, Riwu KHP, Kholik, Mbura YVH, and Zakarias HV (2024). Pattern of antibiotic resistance in *Salmonella sp.* bacteria contaminating fresh faeces of laying hens in Kediri District, West Lombok Regency. Biota, 9(2): 145-154. DOI: https://www.doi.org/10.24002/biota.v9i2.7814

Redweik GAJ, Jochum J, Mellata M (2020). Live bacterial prophylactics in modern poultry. Front Vet Sci. 7: 592312. DOI: https://www.doi.org/10.3389/fvets.2020.592312

Reygaert WC (2018). An overview of the antimicrobial resistance mechanisms of bacteria. AIMS Microbiology, 4(3): 482-501. DOI: https://www.doi.org/10.3934/microbiol.2018.3.482

Rodrigues G, Souza SL, and Franco OL (2022). Antimicrobial Peptides controlling resistant bacteria in animal production. Frontiers in Microbiology, 13: 874153. DOI: https://www.doi.org/10.3389/fmicb.2022.874153

Rousham EK, Unicomb L, and Islam MA (2018). Human, animal and environmental contributors to antibiotic resistance in low-resource settings: Integrating behavioural, epidemiological and One Health approaches. Proceedings of the Royal Society B: Biological Sciences, 285(1876): 20180332. DOI: https://www.doi.org/10.1098/rspb.2018.0332

Sa'adah L (2017). Detection of tetracycline antibiotic residues in chicken eggs from layer farms: Study in Mlonggo Subdistrict, Jepara Regency. Thesis, Muhamadiyah University, Semarang, Indonesia.

Sabdoningrum EK, Hidanah S, Yuniarti WM, Chusniati S, Warsito SH, and Muchtaromah B (2020). Antimicrobial activity of *Phyllantus niruri* extract on avian pathogenic *Escherichia coli* isolated from chicken with colibacillosis symptoms. Research Journal Pharmacy and Technology, 13(4): 1883-1887. DOI: https://www.doi.org/10.5958/0974-360X.2020.00339.X

Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, Rabaan AA, and Alqumber MAA (2023). Antimicrobial resistance: A growing serious threat for global public health. Healthcare, 11(13): 1946. DOI: https://www.doi.org/10.3390/healthcare11131946

Samtiya M, Matthews KR, Dhewa T, and PuniyaAK (2022). Antimicrobial resistance in the food chain: trends, mechanisms, pathways, and possible regulation strategies. Foods, 11(9): 2966. DOI: https://www.doi.org/10.3390/foods11192966

Sattar AA, Chisty NN, Irin N, Uddin MH, HasibFMY, and Hoque MA (2023). Knowledge and practice of antimicrobial usage and resistance among poultry farmers: A systematic review, meta-analysis, and meta-regression. Veterinary Research Communications, 47(3): 1047-1066. DOI: https://www.doi.org/10.1007/s11259-023-10082-5

Serwecińska L (2020). Antimicrobials and antibiotic-resistant bacteria: A risk to the environment and to public health. Water, 12(12): 3313. DOI: https://www.doi.org/10.3390/w12123313

Singh R and Kim K (2025). Environmental occurrence of antibiotic resistance, control measures and challenges in finding therapeutic management. Emerging Contaminants, 11(1): 100440. DOI: https://www.doi.org/10.1016/j.emcon.2024.100440

Sivalingam PL (2019). Detection of antibiotic residues in chicken eggs from traditional markets in Yogyakarta City using the bioassay testing method. Thesis. Gadjahmada University, Indonesia.

Struik PC and Kuyper TW (2017). Sustainable intensification in agriculture: The richer shade of green: A review. Agronomy for Sustainable Development, 37(5): 39. DOI: https://www.doi.org/10.1007/s13593-017-0445-7

Sunartatie T, Safika, Abhirama HR, Citra, Kurnia RS, Putra MA, and Indrawati A (2024). Identification and Antibiotic resistance of *Pasteurella multocida* isolated from infected layer chickens in West Java, Indonesia. Journal of World's Poultry Research, 14(3): 282-290. DOI: https://www.doi.org/10.36380/jwpr.2024.29

Suswati E, Sakinah EN, Firdaus J, and Khoiri A (2023). Resistance profile of bacteria isolated from laying hens manure in Jember regency. Buletin Veteriner Udayana, 15(5): 822-830. DOI: https://www.doi.org/10.24843/bulvet.2023.v15.i05.p17

Suswati E, Pratama DR, and Hermansyah B (2025). Prevalence of Multi-Drug Resistance Escherichia coli in Broiler Chicken Meat in Jember, Indonesia. World Veterinary Journal, 15(1): 79-85. DOI: https://www.doi.org/10.54203/scil.2025.wvj10

Tenaya IWM, Swacita IBN, Sukada IM, Suada I, Mufa RMD, Agustina KK, and Handayani NM (2024). Microbial investigation of animal product hygiene in Bali and Nusa Tenggara of Indonesia. International Journal of Veterinary Science, 13(4): 413-420. DOI: https://www.doi.org/10.47278/journal.ijvs/2023.120

Toghroli R, Hassani L, Aghamolaei T, Sharma M, Sharifi H, and Jajarmi M (2024). Explaining the barriers faced by veterinarians against preventing antimicrobial resistance: An innovative interdisciplinary qualitative study. BMC Infectious Diseases, 24(1): 455. DOI: https://www.doi.org/10.1186/s12879-024-09352-7

Uddin TM, Chakraborty AJ, Khusro A, Zidan BRM, Mitra S, Emran TB, and Koirala N (2021). Antibiotic resistance in microbes: History, mechanisms, therapeutic strategies and future prospects. Journal of Infection and Public Health, 14(12): 1750-1766. DOI: https://www.doi.org/10.1016/j.jiph.2021.10.020

Utari A, Retnowati A, Andriani MD, Anisatun H, Riandi, and Nur E (2018). Trend of antibiotic residue testing results in chicken eggs in Indonesia from 2015-2017. Hamera Zoa, 20: 299-301. Available at: https://journal.ipb.ac.id/hemera/article/view/23916

Wall S (2019). Prevention of antibiotic resistance - An epidemiological scoping review to identify research categories and knowledge gaps. Global Health Action, 12(1): 1756191. DOI: https://www.doi.org/10.1080/16549716.2020.1756191

World bank group (WBG) (2017). Drug-resistant infections: A threat to our economic future. World Bank Group (WBG), Washington. Available at: https://documents1.worldbank.org/curated/en/323311493396993758/pdf/final-report.pdf

Wibisono FJ, Sumiarto B, Untari T, Effendi MH, Permatasari DA, and Witaningrum AM (2020). Antibiotic resistance profile of *Escherichia coli* isolates collected from cloaca swabs on laying hens in Udanawu Sub-District, Blitar District, Indonesia. Ecology, Environment and Conservation Paper, 26: 261-264. Available at: https://www.envirobiotechjournals.com/EEC/26NovSupplIssue2020/EEC-45.pdf

Wibisono FJ, Effendi MH, Tyasningsih W, Rahmaniar RP, Khairullah AR, Kendek IA, Budiastuti B, Rianto V, Nico DC, Kurniasih DAA et al. (2025). Antibiotic resistance profiles of *Escherichia coli* and *Salmonella spp*. isolated from chicken meat sold in traditional markets in Gresik District, East Java, Indonesia. Open Veterinary Journal, 15(5): 2160-2170. DOI: https://www.doi.org/10.5455/OVJ.2025.v15.i5.34

Widyatmanti W, Minasny B, Awanda D, Umarhadi DA, Fatma ZSN, Mahendra WK, and Field DJ (2022). Codification to secure Indonesian peatlands: From policy to practices as revealed by remote sensing analysis. Soil Security, 9: 100080. DOI: https://www.doi.org/10.1016/j.soisec.2022.100080

Witaningrum AM, Wibisono FJ, Permatasari DA, Tyaningsih W, Effendi MH, and Kurniawan F (2020). Potential hazards of antibiotics resistance on *Escherichia coli* isolated from cloacal swab in several layer poultry farms, Blitar, Indonesia. Indian Journal of Public Health Research and Development, 11(3): 2389-2395. DOI: https://www.doi.org/10.37506/ijphrd.v11i3.2764z

Witoko MC, Suardana IW, and Rudyanto MD (2019). Detection of antibiotic residues in chicken eggs at the chicken egg farmers and egg distributors on trading business in Denpasar Municipality. Journal of Veterinary and Animal Sciences, 2(2): 72. DOI: https://www.doi.org/10.24843/jvas.2019.v02.i02.p05

World organization on animal health (WOAH) (2024). Towards a healthier future for all: Progress in animal health to contain antimicrobial resistance. World Organization on Animal Health. DOI: https://www.doi.org/10.20506/ woah.3536

Wong JT, de Bruyn J, Bagnol B, Grieve H, Li M, Pym R, and Alders RG (2017). Small-scale poultry and food security in resource-poor settings: A review. Global Food Security, 15: 43-52. DOI: https://www.doi.org/10.1016/j.gfs.2017.04.003

Zhang T, Nickerson R, Zhang W, Peng X, Shang Y, Zhou Y, and Cheng Z (2024). The impacts of animal agriculture on One Health—Bacterial zoonosis, antimicrobial resistance, and beyond. One Health, 18: 100748. DOI: https://www.doi.org/10.1016/j.onehlt.2024.100748