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Prevalence and Antibiotic Resistance of *Escherichia coli* in Eggs

Abstract

Chicken eggs are a highly nutritious component of the diet, containing abundant proteins, vitamins, minerals, and essential fatty acids. Despite their nutritional advantages, both vertical and horizontal contamination present significant public health concerns. Numerous microbiological investigations have demonstrated that *Escherichia coli* is among the most frequently identified bacteria in eggs. *E. coli*, a pathogenic and zoonotic microorganism, encompasses serotypes capable of inducing severe symptoms in humans. Moreover, the extensive use of high-dose antibiotics for disease prevention in egg production has contributed to the emergence of antibiotic-resistant *E. coli* strains. This review synthesizes recent research regarding the prevalence of *E. coli* in poultry eggs across various continents and countries, as well as the antibiotic resistance profiles of these strains. Presently, understanding the prevalence of *E. coli*, particularly multidrug-resistant strains-which constitute a recognized global threat-and their antibiotic resistance profiles is crucial for protecting public health and fostering sustainability.

Keywords: Antibiotic resistance, egg, *Escherichia coli*, poultry, public health

Yumurtalarda *Escherichia coli* Prevalansı ile Antibiyotik Direnci

Öz

Kanatlı yumurtası, yüksek düzeyde protein içermesinin yanı sıra vitamin, mineral ve temel yağ asitleri açısından da oldukça değerli bir gıda maddesidir. Yumurtanın besleyici düzeyi yüksek olmakla birlikte, vertikal ve horizontal bulaşmalar halk sağlığı açısından risk oluşturmaktadır. Yumurtanın mikrobiyolojisi ile ilgili yapılan çok sayıda çalışma, *Escherichia coli*'nin en sık karşılaşılan bakterilerden biri olduğunu ortaya koymaktadır. Patojen ve zoonoz karakterde bir mikroorganizma olan *E. coli*'nin insanlarda ciddi semptomlara sebep olan serotipleri mevcuttur. Ayrıca, yumurta yetiştiriciliğinde karşılaşılan hastalıkların engellenmesi amacıyla sıklıkla ve yüksek dozda antibiyotik kullanımı sonucunda antibiyotik dirençli *E. coli* suşları ortaya çıkmaktadır. Mevcut derleme çalışması, farklı kıtalarda ve ülkelerde çeşitli kanatlı hayvan yumurtalarında *E. coli* prevalansı üzerine yapılan güncel çalışmaları ve antibiyotik direnç profillerini içermektedir. Günümüzde, küresel tehdit olarak değerlendirilen özellikle çoklu antibiyotik direncine sahip E. coli prevalansı ile antibiyotik direnç profillerinin belirlenmesi, halk sağlığının korunması ve sürdürülebilirlik açısından büyük önem taşımaktadır.

Anahtar kelimeler: Antibiyotik direnci, *Escherichia coli*, halk sağlığı, kanatlı, yumurta

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Introduction

Eggs are widely consumed globally as a valuable source of protein and an essential component of a nutritious diet, owing to their availability and nutritional benefits. Historically, global egg production has steadily increased over the past two decades, with reports indicating that it surpassed 90 million tonnes by 2023. An examination of egg production data across continents reveals that Asia accounts for the largest share, with 57% of the total. Within Asia, China emerges as the leading egg producer, accounting for over 34% of global production, surpassing the second-largest producer. Recent data indicate a continued rise in global egg production, predominantly concentrated in Asia (FAO, 2025). Specifically, an analysis of chicken egg production in Türkiye shows that from January to November 2024-2025, production increased to approximately 18.04 billion eggs. These figures suggest that annual egg production in Türkiye remains stable. The consistent monthly production volumes at the billion-unit level demonstrate Türkiye's capacity to meet domestic demand and export to international markets (TÜİK, 2026).

Although eggs possess inherent protective barriers, contamination-particularly through vertical and horizontal transmission-continues to pose a significant risk to public health (Şencal and Aydın, 2025). Numerous studies have identified *Escherichia coli* (*E. coli*) as one of the most prevalent pathogens in the gastrointestinal tracts of poultry and humans (Neira et al., 2017; Adesiyun et al., 2020)

Considering the high prevalence of *E. coli* on eggshells, there is a significantly increased risk of microbial transfer to the egg contents upon shell rupture (Neira et al., 2017). Nevertheless, the excessive use of antibiotics in egg production introduces challenges, as it may contribute to the emergence and dissemination of multidrug-resistant *E. coli* and other harmful microorganisms. The development of resistance to beta-lactam antibiotics in *E. coli* strains, which have been widely used in recent years, is closely monitored. Such resistant microorganisms may serve as reservoirs of antimicrobial resistance, with the potential to transmit resistance to human pathogens (Akond et al., 2009; Suleymanoglu et al., 2024a).

The aim of this review is to comparatively assess the prevalence of *E.coli* in poultry eggs, antibiotic resistance profiles, and the distribution of resistance genes, based on research conducted across different continents and countries, and to present the current literature in this field from a comprehensive perspective.

The Etiology and Types of Pathogenic *Escherichia coli*

E. coli, a Gram-negative bacterium, is frequently used in experimental studies due to its relevance to human biology and fundamental biological processes. It is among the most prevalent facultative anaerobic microorganisms within the intestinal flora of healthy individuals. Pathogenic strains of *E. coli* may induce food poisoning and diarrhea, particularly in immunocompromised individuals, the elderly, and infants (Begum et al., 2014). While most *E. coli* populations are commensal, certain subpopulations-namely intestinal pathogenic *E. coli* (IPEC) and extraintestinal pathogenic *E. coli* (ExPEC)-are highly pathogenic, causing infections in the intestines and elsewhere in humans and animals (Riley, 2020). Serotypes of intestinal pathogenic *E. coli* (IPEC) include Enteroinvasive *E. coli* (EIEC), Enterotoxigenic *E. coli* (ETEC), Enterohaemorrhagic *E. coli* (EHEC), Enteropathogenic *E. coli* (EPEC), Enteroaggregative *E. coli* (EAEC), and Diffusely Adherent and Adhesion-Capable *E. coli* (DAEC) (CDC, 2025). Strains of ExPEC and avian pathogenic *E. coli* (APEC) represent among the most prevalent bacterial pathogens impacting various poultry species, including broilers, layers, breeders, and turkeys. The presence of ExPEC results in significant economic losses for the global poultry industry and leads to adverse outcomes, including morbidity and mortality rates of up to 20%, reduced

production, and carcass losses of up to 43% at slaughter. APEC is also recognized as a potential foodborne zoonotic pathogen (Kathayat et al., 2021).

Pathways of *Escherichia coli* Contamination in Poultry Eggs

Microbial contamination of eggs occurs via two pathways: vertical and horizontal. Vertical contamination is characterized by the infection of eggs during their formation within the ovary or oviduct. Horizontal contamination occurs when eggs are exposed to faecal bacteria after laying, allowing bacteria to penetrate through the shell membrane. Consequently, microorganisms can penetrate the egg during extended periods of storage and transportation (Chi et al., 2023; Özçevik et al., 2023). Therefore, the consumption of raw or undercooked eggs and egg-containing products may pose significant health risks to humans (Yenilmez et al., 2024).

Prevalence of *Escherichia coli* in Eggs

E. coli is frequently detected on eggshells and is considered an indicator of fecal contamination in poultry eggs. Studies on this subject highlight that eggshell contamination primarily originates from fecal matter and the surrounding poultry environment, with horizontal transmission identified as the principal route of contamination (Chousalkar et al., 2010; Jevinová et al., 2021). Furthermore, it has been documented that *E. coli* can persist on the eggshell surface and, under suitable conditions, may penetrate the shell and membranes, thereby potentially posing a risk to the egg contents (Chousalkar et al., 2021).

Research on the prevalence of *E. coli* in eggs across continents has shown that contamination is widespread, affecting eggs from multiple poultry species, including chickens, ducks, and quails. In regions such as Asia and Africa, higher incidences of *E. coli* contamination on eggshells have been documented, particularly in traditional and small-scale production systems where close contact with fecal matter and limited biosecurity measures are prevalent (Hossain et al., 2021; Mahmood and Hadi, 2022). Similar trends have been observed internationally, with *E. coli* detected on eggshells and, in certain instances, within the egg contents. Although generally less prevalent in intensive commercial systems with enhanced hygiene practices (Adesiyun et al., 2020), these findings highlight the critical importance of continual monitoring. Furthermore, multiple studies conducted in the Americas have explicitly focused on antibiotic resistance patterns and the dissemination of extended-spectrum beta-lactamase (ESBL) genes.

Table 1: The prevalence of *Escherichia coli* in poultry eggs from several continents.

Continent	Country	Sample	Prevalence of *E.coli* %	Reference
EUROPA	Türkiye	Eggshell	18.6% (65/350)	Guran et al., 2023
	Türkiye	Table Egg	12.5% (15/120)	Suleymanoglu et al., 2024b
	Türkiye	Eggshell	6% (12/200)	Karadal et al., 2018
	Spain	Hen egghell	15% (27/180)	Burgos et al., 2016
AMERICA	USA	Eggshell	11.9% (30/252)	Kilonzo-Nthenge et al., 2016
		Egg content	5.2% (13/252)	
	Argentina	Eggshell	<1% (0/6)	González et al., 2025
ASIA	China	Chicken egg	15.56%(14/90)	Chen et al., 2019
		Goose egg	15.56%(14/90)	
		Ostrich egg	76.67%(23/30)	
		Duck egg	12.22%(11/90)	
		Turkey egg	3.33%(3/90)	
		Quail egg	2.22%(2/90)	
	South India	Table egg	28.5% (239/840)	Vinayananda et al., 2017
	Bangladesh	Chicken egg	38.89%(70/180)	Hossain et al., 2021
	Pakistan	Chicken egg	33.3% (10/30)	
		Duck egg	60%(6/10)	Rafiq et al., 2024
	Bangladesh	Table egg	34.64% (70/200)	Islam et al., 2018
AFRICA	South Africa	Table Eggshell	49%(96/196)	Adesiyun et al., 2020
		Egg content	2%(4/196)	
	Nigeria	Table Eggshell	%9.8(7/72)	Atoyebi et al., 2019
	Egypt	Chicken egg	26%(13/50)	Elafify et al., 2016
		Duck egg	36%(18/100)	

Antibiotic Resistance in *Escherichia coli*

The use of antibiotics offers advantages, including treating diseases and enhancing growth in livestock farming. Nevertheless, antibiotic resistance exerts a detrimental impact on human health, both directly and indirectly, through food-related pathways (Boz and Aydın, 2026). On a global scale, multidrug-resistant strains of *E. coli* have been identified in isolates from both humans and animals across different regions (Amara et al., 1995). When comparing contamination rates of eggshells with those of egg contents, *E. coli* isolates demonstrated complete resistance to penicillin G at a rate of 100%, to ceftazidime at 95.6%, and to amoxicillin at 72.2%. The prevalence of antibiotic resistance varies significantly across regions, with higher rates reported in isolates from Asia and Africa (Hinson et al., 2025).

Table 2: Antibiotic resistance patterns and ESBL/antimicrobial resistance genes reported in egg-associated *E. coli* isolates

Country	Antibiotic resistance rates (%) of *E. coli* isolates	ESBL/ genes	Reference
Türkiye	AMP 34%(12/35), AMC 22.8% (8/35)	Not investigated	Guran et al.,2023
Türkiye	AMP 80%(12/15, TET 66.6%(10/15), CHL 66.6%(10/15),	*bla*$_{TEM}$ 100%(15/15) *bla*$_{CTX-M}$ 20%(3/15)	Suleymanoglu et al., 2024b
Spain	AMP 37.03%(10/27), STR 37.03%(10/27), TET 37.03% (10/27)	*bla*$_{CTX-M-2}$ 22.22%(6/27) *bla*$_{TEM}$(1/27) *bla*$_{PSE}$(1/27)	Burgos et al., 2016
USA	ERY 48.5%(15/30), AMP 44%(13/30), TET 29.9%(9/30)	Not investigated	Kilonzo-Nthenge et al., 2016
Argentina	TET 97.5% (39/40), CIP 82.5% (33/40)	*bla*$_{CTX-M-2}$ 75%(33/44) *bla*$_{TEM}$ *13.6%* (6/44) *bla*$_{SHV}$ *6.8%* (3/44) *bla*$_{OXA-2}$ *4.5%* (2/44)	González et al., 2025
South India	OXA 100%, NEO 25%, CFR 57.5%, FOX 27.5%	Not investigated	Vinayananda et al., 2017
Bangladesh	AMP 71.4% (5/7), ERY 71.4% (5/7), TET 57.1% (4/7)	Not investigated	Hossain et al., 2021
Bangladesh	TET 100% (9/9), AMC 88.89%(8/9), AMP 77.78% (7/9)	Not investigated	Islam et al., 2018
Nigeria	AMP 100%(7/7), AUG 100%(7/7) CAZ 100%(7/7)	Not investigated	Atoyebi et al., 2019

Ampicillin: (AMP); Amoxicillin: (AMX); Amoxicillin–clavulanic acid: (AMC); Augmentin: (AUG); Ceftriaxone: (CFR); Ceftazidime: (CAZ); Cefoxitin: (FOX); Ciprofloxacin: (CIP); Chloramphenicol: (CHL); Erythromycin: (ERY); Oxacillin: (OXA); Tetracycline: (TET). ESBL: Extended-Spectrum Beta-Lactamases

An evaluation of the studies presented in Tables 1 and 2 reveals that *E. coli* contamination in poultry eggs has been reported with varying prevalence rates worldwide. In studies conducted in Türkiye, the predominant detection of *E. coli* on eggshells suggests that the contamination may be of environmental origin (Karadal et al., 2021). Similarly, a study conducted in Diyarbakır reported a higher prevalence of *E. coli* in free-range chicken eggs and in samples packaged in foam (Guran et al., 2023). When both studies are considered together, it becomes clear that the production system and packaging conditions may be decisive factors in eggshell contamination. Furthermore, in the study by Guran et al. (2023), the evaluation of antibiotic susceptibility tests using MIC-based methods according to CLSI(Clinical and Laboratory Standards Institute) criteria and the identification of the most common resistance against ampicillin distinguishes this methodologically from the study by Karadal et al. (2021), as it reveals not only contamination but also the antibiotic resistance profile.

Another study conducted in Türkiye reported that isolates were confirmed using molecular

methods and that a high prevalence of multidrug resistance was observed (Suleymanoglu et al., 2024b). This suggests that, compared with traditional culture-based studies, molecular analyses may offer a significant advantage in elucidating the genetic mechanisms underlying antibiotic resistance. Similarly, research across different components of the poultry production chain has revealed that antibiotic-resistant *E. coli* can be found not only in eggs but also at various stages of poultry product processing. For instance, a study investigating the prevalence of ESBL-producing *E. coli* (48.5%, 101/208) in raw chicken meat samples collected from diverse retail outlets in Istanbul confirmed the isolates by PCR, with resistance to amoxicillin-clavulanic acid being most common. The presence of beta-lactamase genes and mobilized colistin resistance genes was examined in 18 isolates (17.8%) exhibiting phenotypic ESBL resistance, as determined by the double disc synergy test (DDST). The most frequently detected gene group was bla_{TEM} (97.02%), followed by $bla_{\text{CTX-M}}$ (45.5%), bla_{SHV} (9.9%), and $bla_{\text{OXA-2}}$ (0.9%) (Aydın et al., 2024). When these findings are considered collectively, it becomes apparent that antibiotic-resistant bacteria have the potential to disseminate throughout the poultry production continuum. Studies conducted across Europe generally focus not only on estimating the prevalence of *E. coli* but also on exploring virulence factors and antibiotic resistance genes at the molecular level. A study in Spain reported that a substantial proportion of isolates carried various resistance genes, including β-lactam and tetracycline resistance (Burgos et al., 2016). Conversely, a study in Slovakia indicated that contamination was more closely associated with production systems and storage conditions (Petrovič et al., 2024). When these two studies are considered together, it is evident that European research addresses both production practices and molecular resistance mechanisms.

Research conducted in the Americas similarly indicates that contamination is predominantly concentrated on the eggshell. A study conducted in the United States reported higher contamination rates on eggshells than in the contents (Kilonzo-Nthenge et al., 2016). In contrast, a study conducted in Argentina reported that the $bla_{\text{CTX-M}}$ gene group was particularly prevalent among ESBL-producing *E. coli* isolates (González et al., 2025). This suggests that studies in the Americas have focused more on antibiotic resistance patterns and the prevalence of ESBL genes.

Research conducted in Asia, however, suggests that differences between poultry species may influence contamination levels. A comparative study conducted in China reported that the prevalence of *E. coli* in eggs from different poultry species varies, with the highest prevalence observed in ostrich eggs (Chen et al., 2019). In contrast, studies conducted in India, Bangladesh, and Pakistan have reported that contamination rates in chicken eggs can vary depending on the production system and environmental factors (Khan et al., 2016; Vinayananda et al., 2017; Islam et al., 2018; Hossain et al., 2021). Furthermore, a study in Pakistan that also examined environmental samples indicated that the production environment could serve as a significant reservoir for contamination (Sohaib et al., 2023). Conversely, a study conducted in Taiwan reported that the prevalence of pathogenic *E. coli* in retail eggs was very low (Hsu et al., 2023). When these findings are considered collectively, it is evident that research within Asia has emphasized elucidating the effects of both poultry species and environmental factors on contamination.

Research conducted on the African continent indicates that contamination is predominantly localized on the surface of eggshells. A study carried out in South Africa reported an increased prevalence of *E. coli* on the shell surface (Adesiyun et al., 2020), while it has been documented that *E. coli* O157:H7 strains isolated in Nigeria exhibit multidrug resistance (Atoyebi et al., 2019). Studies in Egypt have reported that some isolates possess virulence genes such as *eae*, *stx*1, *stx*2, and *hly*A, and that the prevalence of *E. coli* in duck eggs exceeds that observed in chicken eggs (Elafify et al., 2016; Fahim et al., 2021; Mo'ataz et al., 2021). These findings suggest that biological differences among

poultry species may influence contamination levels.

An analysis of research studies conducted across various continents indicates that *E. coli* contamination in poultry eggs is pervasive. Furthermore, reported prevalence rates may fluctuate due to factors such as the production system, poultry species, environmental hygiene conditions, and storage procedures. Nevertheless, methodological differences among studies may also contribute to variability in reported prevalence rates.

For example, there are significant differences between studies regarding sample size, bacterial isolation methods, antibiotic susceptibility testing criteria (CLSI/EUCAST), and molecular analysis techniques. It has been reported that studies with larger sample sizes may yield more reliable prevalence estimates, whereas studies with smaller sample sizes may yield more variable results. Similarly, whilst some studies employ classical culture methods based on selective media and biochemical identification techniques (Vinayananda et al., 2017; Islam et al., 2018; Atoyebi et al., 2019; Hossain et al., 2021), other studies have utilised molecular techniques such as PCR for bacterial confirmation and the identification of resistance genes (Burgos et al., 2016; Süleymanoğlu et al., 2024b; González et al., 2025). Studies employing molecular validation methods can provide more detailed data, particularly for identifying antibiotic resistance genes.

Different approaches are also employed in antibiotic susceptibility testing. Whilst some studies utilise systems based on the minimum inhibitory concentration (MIC) according to CLSI criteria (Guran et al., 2023; Süleymanoğlu et al., 2024b), other studies have applied the Kirby-Bauer disc diffusion method (Vinayananda et al., 2017; Islam et al., 2018; Atoyebi et al., 2019; Hossain et al., 2021). As these methodological differences may lead to variation in antibiotic resistance rates, it is important to consider the methods used when interpreting the prevalence and resistance data reported in different studies.

Protection and Control

Maintaining high standards of hygiene and implementing HACCP protocols throughout the food production chain are fundamental for preventing food contamination and ensuring consumer safety. Furthermore, appropriate procedures for food processing and preparation in domestic environments are of considerable significance (EFSA, 2026). The crucial role of cross-contamination in the transmission of foodborne illnesses highlights the importance of rigorous food safety measures. In addressing *E. coli*, including antibiotic-resistant strains, collaboration between human and veterinary medical professionals is essential within a framework of preventive medicine, in accordance with the "One Health" principle (Aydın and Süleymanoğlu, 2025).

Faecal-origin bacteria can remain viable on eggshells for extended periods and, under suitable conditions, can penetrate the egg contents. Indeed, a study on *Salmonella enteritidis* reported that the pathogen remained viable on the shell surface for 21 days in non-disinfected eggs and penetrated the egg contents during storage. Accordingly, the possibility of a similar risk for *E. coli*, a faecal-origin indicator microorganism, highlights the necessity of effective disinfection practices on eggshells (Aksu et al., 2006). While antibiotics and vaccines are used to control APEC infections in poultry, their effectiveness is limited by antibiotic resistance and the presence of multiple serotypes, particularly when infections originate in soil. Antibiotic-resistant strains can spread to humans via animals, foodstuffs, or the environment. Probiotics and antimicrobial peptides are being studied as alternatives to antibiotics for combating APEC. In one study, researchers investigated whether a live Salmonella vaccine (RASV), probiotics, or both could protect White Leghorn chicks from APEC and Salmonella. The chicks were divided into four groups, and blood samples were collected at the conclusion of the study. The group that received both probiotics and the vaccine demonstrated the strongest immune response and the best protection against both strains and APEC O1. These results suggest that

administering probiotics with the RASV vaccine can enhance immunity against *E. coli* infections and reduce their severity (Redweik et al., 2020). However, high levels of contamination by multi-antibiotic-resistant *E. coli* continue to threaten public health, underscoring the necessity of further research on how to monitor and control these bacteria in food (Kuzeubayeva et al., 2024).

Conclusion

Across continents, *E. co*li contamination in poultry eggs is reported globally, with prevalence rates potentially varying by production systems, hygiene conditions, and environmental factors. A considerable proportion of these studies indicate that contamination is predominantly localized on the eggshell. Nevertheless, most research in the literature focuses on chicken eggs, whereas investigations involving eggs from other poultry species, such as ducks, geese, quails, or ostriches, are limited. This underscores the need for more comprehensive research on Escherichia coli contamination and antimicrobial resistance profiles in eggs from diverse poultry species.

When evaluated in terms of antibiotic resistance profiles, numerous studies demonstrate that resistance, especially to β-lactam and tetracycline antibiotics, is widespread. Furthermore, the identification of resistance genes such as bla_{TEM}, $bla_{\text{CTX-M}}$, and *tet* suggests that poultry eggs may act as a potential reservoir for the dissemination of antimicrobial resistance genes.

It is also essential to recognize that methodological variations among the studies may influence the reported prevalence figures.

Therefore, it is important for future research to employ broader sampling strategies and to investigate the molecular mechanisms of antibiotic resistance in greater detail. Furthermore, strengthening biosecurity practices in poultry production systems, controlling antibiotic use, and implementing regular microbiological monitoring programmes are of critical importance for food safety and public health.

This review study provides a comprehensive overview of the current literature on the prevalence of *E. coli*, antibiotic resistance patterns, and the distribution of resistance genes reported in poultry eggs, by conducting a comparative evaluation of research carried out across different continents. The findings obtained in this context contribute to a better understanding of antimicrobial resistance trends within the poultry production chain, serving as an important reference for future research and food safety strategies.



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