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BACTERIAL AGENTS INVOLVED IN POULTRY MEAT CONTAMINATION: PATHOGEN DIVERSITY, TRANSMISSION ROUTES AND FOOD SAFETY IMPLICATIONS

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Abstract

Poultry meat is an important source of protein and very commonly consumed by the population globally. The bacterial agents involved in its contamination, and which pose a risk to public health, leading to serious diseases that can be transmitted through food, are represented by: Salmonella, Campylobacter, Escherichia coli and Listeria monocytogenes. This study will present the transmission routes of these pathogens, the determinants of their persistence focusing on cross-contamination, poor hygiene of workspaces and environmental factors such as deviations of humidity and temperature. This article explores various strategies to reduce bacterial contamination in poultry, focusing on improving hygiene protocols, refining processing techniques, and enforcing stricter food safety standards. These actions are essential for safeguarding poultry meat and minimizing the public health risks posed by bacterial pathogens in the poultry industry.

***Key words**: bacterial contaminants, food safety, poultry meat.*

INTRODUCTION

Poultry meat is a crucial dietary staple and an excellent source of high-quality protein, favoured worldwide for its affordability, versatility, and nutritional value. Recent data show that global consumption has reached an average of 21.9 kilograms per capita annually (Authority, 2016).

The safety of poultry products remains a critical concern due to their vulnerability to bacterial contamination. This contamination poses a significant public health risk, as it can result in the transmission of foodborne illnesses caused by pathogens such as *Salmonella spp*., *Campylobacter* spp., *Escherichia coli*, and *Listeria monocytogenes (*Mor-Mur et al., 2010). The most common *Salmonella* serovars identified in poultry are *Salmonella typhimurium* and *Salmonella enteritidis* (Ricke, 2020).

Contaminated poultry carcasses can also introduce other microorganisms, such as *Clostridium perfringens* and certain *Listeria* species, into the human food chain (Mor-Mur et al., 2010). These bacteria are among the most common agents associated with foodborne outbreaks, with severe health consequences ranging from gastrointestinal illness to systemic infections and, in vulnerable populations, even death (Bintsis, 2017).

The pathways through which these pathogens contaminate poultry meat are complex and multifaceted. Contamination can occur at any point along the production chain, from on-farm conditions to slaughter, processing, distribution, and eventual handling by consumers (Göksoy et al., 2004; Mor-Mur et al., 2010) (Figure 1).

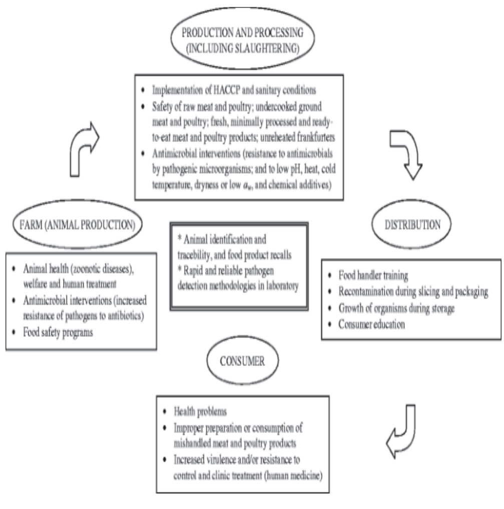

Figure 1. Diagram of potential infection risks in the food chain

Key factors contributing to the persistence and proliferation of these pathogens include inadequate hygiene practices, cross-contamination during processing, and environmental influences such as temperature and humidity fluctuations. Together, these elements create a challenging environment for ensuring poultry meat safety (Alegbeleye et al., 2018).

This study examines the transmission routes of these bacterial pathogens, highlighting critical control points where contamination is most likely to occur. It also explores the determinants that enhance their persistence, with a particular focus on poor workspace hygiene, lapses in sanitation protocols, and the impact of environmental factors. Additionally, the article discusses a range of strategies aimed at reducing bacterial contamination in poultry products.

These strategies include improving hygiene practices throughout the production chain, optimizing processing techniques, and enforcing stricter food safety standards (Martin, et al., 2024).

By addressing these challenges and implementing effective control measures, significant progress can be made toward safeguarding the safety of poultry meat, thus reducing the burden of foodborne illnesses and protecting public health on a global scale (Rouger et al., 2017).

Another significant component in the context of infections is the meat storage practices in commercial units, where refrigeration temperature regulations are not followed. Additionally, another major cause stems from consumer behaviour after purchasing chicken meat, in the context of changes that can occur during transportation, storage, or even from preparation by cooking at improper temperatures (Jackson et al., 2013; Sauter, 1987). These factors play a crucial role in increasing the risk of contamination with the two main bacterial agents associated with chicken meat, namely *Salmonella* and *Campylobacter* (Ovai et al., 2021).

Salmonellosis

Salmonellosis is an infectious disease caused by bacteria of the *Salmonella* genus, which encompasses more than 2,500 serotypes. Among these, two highly pathogenic serotypes primarily affect poultry and are commonly found in certain regions of Central and South America. In most cases, motile *Salmonella* serotypes are not pathogenic to poultry under normal conditions (Lamichhane et al., 2024).

Nevertheless, immunosuppressed birds or very young chicks may be susceptible to infection, particularly when exposed to a high bacterial load (Suzuki, 1994).

A variety of avian species, such as turkeys, quails, geese, ducks, and small domestic birds (e.g., roosters, pheasants, grouse), are susceptible to *Salmonella* infection. These birds may exhibit diverse clinical forms of the disease, ranging from acute to chronic infections, and some individuals may act as asymptomatic carriers (Wibisono et al., 2020) The latter play a significant role in maintaining and spreading the pathogen within avian populations and, potentially, to humans (Wibisono et al., 2020).

Colibacillosis

Colibacillosis is a localized or systemic infection caused by avian pathogenic *Escherichia coli* (APEC). *E. coli* are Gram-negative, facultatively anaerobic bacilli capable of surviving in both aerobic and anaerobic environments, depending on external conditions. Although typically part of the normal intestinal microbiota in birds, these microorganisms can become pathogenic under certain circumstances (Nolan et al., 2015).

The management of colibacillosis in the poultry industry remains a major challenge, primarily due to the complexity of the contributing factors. A critical concern is the emergence and spread of antimicrobial-resistant strains of avian pathogenic *Escherichia coli*. This issue is closely associated with the frequent and often improper use of antibiotics in poultry farms, which promotes the selection of resistant bacterial populations (Redweik et al., 2020).

Furthermore, international regulations particularly those enforced within the European Union impose strict limitations on the use of antimicrobial agents in food-producing animals. While these legislative measures aim to prevent the transfer of resistance genes to human pathogens, they also significantly restrict the therapeutic options available for controlling bacterial infections in poultry (Nolan et al., 2015).

MATERIALS AND METHODS

In this research, a total of 27 relevant bibliographic sources were consulted, addressing bacterial agents involved in poultry meat contamination, exploring pathogen diversity, transmission routes, and food safety implications. The source selection process was carried out according to strict criteria, ensuring the inclusion of the most relevant and up-to-date studies in the field.

The selected studies were published between 1987 and 2024, thus encompassing both foundational research and the latest scientific advancements in the field.

The following academic databases were used to identify sources: *PubMed, ScienceDirect and Google Scholar*. These databases are recognized for the quality and relevance of the scientific publications they index, ensuring access to high-quality, current works.

During the literature search, keywords such as bacterial contamination, poultry meat, *Salmonella*, *Campylobacter*, pathogen diversity, transmission routes, food safety, meat processing, antibiotic resistance, and public health were used. These key words were selected to cover a wide range of topics relevant to the research theme.

Articles published in peer-reviewed scientific journals were selected, analysing aspects related to bacterial contamination of poultry meat, pathogen transmission mechanisms, bacterial diversity, and food safety risks. Relevant studies from the fields of food microbiology, public health, and meat processing technologies were included.

Papers that did not focus directly on bacterial agents or that addressed only pathogens from other food sources were excluded.

A systematic literature review was conducted to identify and analyse studies investigating the same bacterial agents involved in poultry meat contamination. Each source was evaluated based on the relevance and quality of the data presented, and the extracted information was compared to provide a comprehensive overview of the topic.

The information obtained from the selected sources was analysed comparatively to identify patterns and variations in pathogen diversity, their transmission routes, and contamination prevention measures.

The implications for food safety were addressed, including public health risks associated with bacterial contamination and the recommended control measures in the industry and poultry meat handling process.

This selection and analysis methodology allowed for a comprehensive perspective on the bacterial agents involved in poultry meat contamination, their transmission mechanisms, and their impact on food safety.

RESULTS AND DISCUSSIONS

Although infections caused by *Salmonella* and *Campylobacter* have a high incidence within the population, *Campylobacter jejuni* and *Campylobacter coli* are also involved; these bacterial agents cause gastrointestinal pathologies through the consumption of contaminated chicken meat. In intervention strategies for preventing infections, countries adopt different practices as it has been found that the reservoir in urban environments is poultry, which are not necessarily implicated in infections in rural settings (Skarp et al., 2015).

Various intervention strategies have been developed to limit *Campylobacter* colonization in poultry, demonstrating efficacy in both experimental studies and commercial applications. Among these, the administration of probiotics, in particular strains of *Lactobacillus salivarius* and *Lactobacillus reuteri*, has been shown to be effective in inhibiting the growth of *Campylobacter jejuni* and *Campylobacter coli*, most likely through competitive exclusion mechanisms and secretion of antimicrobial compounds (Neijat et al., 2018). Although no commercially available vaccines are currently in widespread use against *Campylobacter* infections, experimental research on immunoprophylaxis, particularly studies focusing on conjugate vaccines utilizing enterobactin as antigen, has demonstrated promising efficacy in reducing intestinal colonization. These findings highlight the considerable potential for developing targeted immunization strategies aimed at the prevention of *Campylobacter* infections (Meunier et al., 2016).

Contamination and transmission routes

Pathogens can localize in various bird organs, such as the skin, lungs, digestive tract, and even the feathers, making contamination possible during the slaughtering process, with a risk of carcass contamination. Although the practices in this slaughtering process can vary depending on the size of the facility, there are common procedures in poultry slaughtering, such as the use of water baths equipped with electrical currents for stunning the birds and the feather removal stage. Due to the small size of the birds, manoeuvrability can sometimes be limited compared to larger animals, which restricts the use of mechanized equipment, increasing the likelihood of cross-contamination (Figure 2) (Rouger et al., 2017).

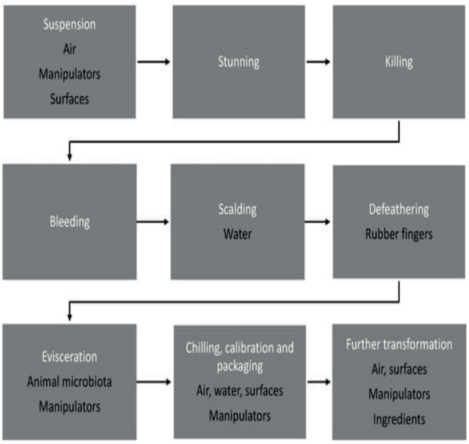

Figure 2. Diagram of the steps in the poultry slaughtering process and associated contamination routes (after, Rouger et al., 2017)

The anatomical and morphological particularities of poultry have necessitated the advancement of dedicated processing technologies capable of accommodating the small size and structural fragility of these animals. In contemporary poultry processing facilities, automation plays a crucial role in enhancing hygienic standards and minimizing microbial hazards. Nevertheless, the efficiency of such automated systems is contingent upon their precise calibration to account for inter-bird variability in size and conformation. Processing steps such as defeathering and evisceration demand high levels of synchronization and mechanical precision to avoid compromising carcass integrity or causing the rupture of visceral organs, events that significantly increase the risk of contamination with enteropathogens such as *Campylobacter* and *Salmonella*.

To address these operational challenges, certain processing facilities have adopted pre-slaughter size sorting mechanisms and employ modular or adjustable equipment systems that can be fine-tuned to match the specific anatomical profiles of poultry carcasses.

Furthermore, the implementation of enhanced sanitation protocols, alongside real-time monitoring of critical control points (CCPs), has become a standardized approach in modern poultry abattoirs. These measures are aimed at mitigating the elevated risk of cross-contamination associated with the automation of processing lines handling small-bodied carcasses (Barbut et al., 2020).

Infection of poultry with *Salmonella* can occur either through direct contact with other carrier birds or through contact with pests, such as rodents. Additionally, another way of transmission can occur indirectly through contaminated bedding, drinking water, or feed

Under favourable environmental conditions, such as room temperature, *Salmonella* spp. has the ability to form a biofilm, giving it increased microbial resistance on work surfaces in slaughterhouses and food processing facilities (Figure 3) (Shaji et al., 2023).

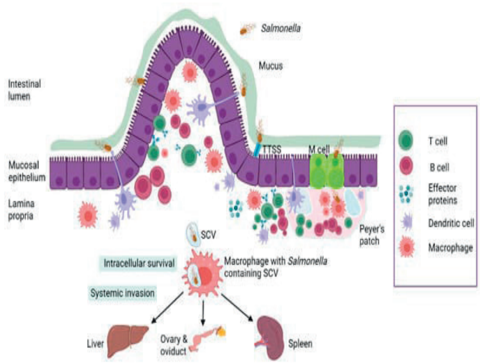

Figure 3. Schematic illustration of *Salmonella* pathogenesis in poultry (after, Shaji et al., 2023)

The transmission of *Campylobacter* spp. to humans occurs through insufficient cooking of chicken meat. It is known that even a small infectious dose can cause human infection, although it is well known that this bacterium does not multiply in food. Among the species, *Campylobacter jejuni* is the most frequently associated with human gastroenteritis, followed by *Campylobacter coli* (Shaji et al., 2023).

Prevalence and antimicrobial resistance

Listeria monocytogenes represents a significant though sometimes underestimated hazard in poultry products, with recent studies revealing concerning patterns of prevalence and antimicrobial resistance. Research examining various poultry meats, including chicken, duck, quail, and turkey, found *Listeria* spp. in 24.46% of samples, with *L. monocytogenes* specifically detected in 10.32% of samples. *L. monocytogenes* was identified as the predominant *Listeria* species in chicken and quail meat, while other *Listeria* species, such as *Listeria innocua and Listeria selligeri* predominated in duck and turkey products, highlighting the variable ecology of this pathogen across different poultry types. Of particular concern is the high prevalence of antimicrobial resistance observed in *Listeria* isolates from poultry meat. Research has revealed that 55.93% of *Listeria* strains isolated from poultry and pork samples demonstrated multi-resistance, defined as resistance to three or more families of antibiotics. The highest rates of multi-resistance were observed in *L. monocytogenes* (73.68%) and *L. innocua* (70.59%), followed by *L. ivanovii* (50%). This widespread antimicrobial resistance significantly complicates the management of listeriosis in both humans and animals. A particularly troubling aspect is the resistance observed against several key classes of antibiotics, including β-lactams (such as ampicillin and penicillin G), aminoglycosides (such as gentamicin and streptomycin), as well as macrolides and tetracyclines. This pattern of resistance complicates therapeutic approaches, especially in severe cases of listeriosis, where β-lactams and aminoglycosides constitute the cornerstone of antimicrobial treatment in both veterinary and human medicine (Çadirci et al., 2023).

This resistance pattern underscores the need for enhanced control measures throughout the poultry production chain, including improved handling practices, thorough cooking, and effective cleaning and disinfection protocols to prevent cross-contamination (Çadirci et al., 2023).

The observed antimicrobial resistance patterns highlight the pressing necessity for a comprehensive reinforcement of control strategies throughout the poultry production chain. While traditional interventions, such as enhanced hygiene during handling, proper thermal processing, and stringent sanitation measures remain foundational in preventing cross-contamination, the adoption of smart technologies in modern processing environments is becoming increasingly pivotal. These advancements include the deployment of real-time biosensor-based monitoring systems for early microbial detection, analytical software capable of processing large datasets to identify deviations from hygienic norms, and automated control mechanisms that dynamically adjust key processing parameters (e.g., temperature, pressure, or disinfectant dosage) in response to identified risks. The integration of such intelligent, adaptive systems not only fortifies food safety protocols but also enables a shift toward proactive and predictive risk management in poultry processing operations (George & George, 2023).

The emergence of highly resistant *Listeria* strains in poultry products represents an evolving food safety challenge that requires heightened vigilance (Çadirci et al., 2023).

Clostridium perfringens has emerged as a significant concern in poultry production, particularly following changes in antimicrobial use practices. The incidence of *C. perfringens*-associated necrotic enteritis in poultry has notably increased in countries that have discontinued antibiotic growth promoters, representing an unintended consequence of efforts to reduce antimicrobial use in animal production. This trend highlights how changes in production practices can influence the emergence or resurgence of bacterial pathogens (Çadirci et al., 2023).

The mechanisms of *C. perfringens* pathogenicity in poultry involve complex interactions between the bacterium and its host environment. Necrotic enteritis and subclinical infections are primarily caused by *C. perfringens* type A, which produces alpha toxin, and to a lesser extent type C, which produces both alpha and beta toxins. Some strains of *C.*

perfringens type A also produce an enterotoxin during sporulation that is responsible for foodborne illness in humans, establishing a clear link between poultry health and human food safety concerns (Van Immerseel et al., 2004).

Foodborne illness caused by *Clostridium perfringens* in humans is predominantly linked to the consumption of inadequately cooked or mishandled meat products, especially those with high bacterial loads, such as poultry and beef (Dolan et al., 2015).

Symptoms of this condition typically include abdominal cramps and diarrhoea, which manifest within six to 24 hours following the ingestion of contaminated food. The primary causative agent of this illness is the enterotoxin produced by *C. perfringens* during sporulation, which disrupts the epithelial cells of the intestine, resulting in gastroenteritis. *C. perfringens* is capable of proliferating in food that is stored at improper temperatures, particularly in large quantities of food that are inadequately refrigerated or held for extended periods. This creates an optimal environment for bacterial growth and toxin production. Although the illness is generally self-limiting, more severe manifestations can occur, particularly among vulnerable groups such as the elderly or immunocompromised individuals, leading to significant health complications. To mitigate the risks associated with *C. perfringens* contamination, it is crucial to adopt appropriate food handling, cooking, and storage practices to ensure food safety (Gotfried, 2023).

Food safety implications and future directions

The emergence and underestimation of bacterial pathogens in poultry meat present significant challenges for food safety systems worldwide. The high prevalence of antimicrobial resistance, particularly in *Listeria monocytogenes* and APEC (Avian Pathogenic *Escherichia coli*), complicates treatment options for human infections acquired through contaminated poultry products (Martinez-Laorden et al., 2024).

Natural Antimicrobials and Alternative Compounds

The application of bacteriocins (antimicrobial peptides) and biosurfactants derived from lactic acid bacteria for the inhibition of *Salmonella* and *Campylobacter* on the surface of fresh meat. These bio compounds offer an effective alternative to chemical preservatives, contributing to enhanced food safety while minimizing potential health risks associated with synthetic additives.

The integration of silver nanoparticles or zinc oxide into active packaging systems, which release metal ions capable of disrupting bacterial biofilms. This innovative approach offers an additional strategy for controlling microbial contamination in food products, thereby improving the preservation and safety of perishable goods (Chowdhury, Ashrafudoulla, Mevo, Mizan, Park, & Ha, 2023).

Advanced Vaccination

Oral vaccines based on genetically modified strains of *Escherichia coli* and *Salmonella* for stimulating mucosal immunity in poultry and reducing intestinal colonization (Redweik et al., 2020).

Phage Therapy in Meat Processing

The implementation of bacteriophage cocktails specifically targeting *Salmonella* and *Listeria* during the final stages of meat packaging represents a promising biocontrol strategy. This approach enables the selective elimination of pathogenic bacteria without compromising the sensory or nutritional quality of the final product, thereby enhancing food safety through a targeted, residue-free intervention (Abreu et al., 2023).

Intelligent Decontamination Systems Enzymes and Antimicrobial Coatings

The use of lipases and proteases to degrade biofilms on processing equipment, combined with edible films infused with essential oils (e.g., oregano oil) (Chowdhury et al., 2023).

CONCLUSIONS

The significant public health burden associated with bacterial contamination of poultry meat necessitates continued research and implementation of effective control strategies across the entire production chain.

While substantial progress has been achieved in understanding the epidemiology and transmission dynamics of major pathogens like

Campylobacter and *Salmonella*, emerging and underestimated pathogens such as *Listeria monocytogenes* and *Clostridium perfringens* warrant increased attention.

The complexity of contamination sources and transmission routes underscores the importance of integrated approaches combining interventions at farm, processing, retail, and consumer levels.

Future research directions should focus on developing improved detection methods for rapid identification of contaminated products, advancing our understanding of pathogen ecology throughout the production chain, and evaluating the efficacy and cost-effectiveness of various intervention strategies in different production contexts.

Additionally, the increasing global poultry meat trade necessitates harmonized approaches to food safety standards and surveillance systems to effectively monitor and control bacterial pathogens across international boundaries.

As poultry consumption continues to increase worldwide, effective control of bacterial contamination remains essential for protecting public health and ensuring consumer confidence in poultry products.

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