Avian Salmonellosis and Public Health Concerns

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ABSTRACT

Avian Salmonellosis is caused by bacteria from the genus Salmonella species. Intensive poultry production has, regrettably, served as the catalyst for the increased spread of salmonellosis. A noteworthy characteristic of this bacteria is its horizontal and vertical transmission in birds. It is transmitted to humans through the food chain, making this a topic of concern for public health and surveillance. The human consequences of salmonellosis are manifold, ranging from the discomfort of gastroenteritis, watery diarrhoea, and abdominal pain to more ominous manifestations such as headache, nausea, vomiting, fever, and occasionally meningitis, which can sometimes culminate in death. Comprehensive surveillance at local, national, and international levels is necessary to design effective control strategies for salmonellosis. Mitigation strategies for salmonellosis are multi-faceted tasks that include strict biosecurity and vaccination along with the use of probiotics, prebiotics, indispensable amino acids, organic acids, and essential oils in the feed of poultry, which can lessen the contamination of poultry products.

Key words: Avian Salmonellosis, Transmission, Surveillance, Public Health, Prevention

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1. INTRODUCTION

Avian Salmonellosis is caused by a bacterium belonging to the genus Salmonella (S) species. The proliferation and spread of such microorganisms of great importance have been favored by rigorous poultry farming owing to the extension and development of the market. This has led to keeping animals in commercial poultry in such large aggregations (Stella et al. 2021). Avian Salmonellosis proves to be the most damaging disease globally as poultry rearing and farming is progressing. In poultry, contaminated eggs are mainly associated with the cause of fowl typhoid and pullorum disease via its spread from one generation to the next (Wigley et al. 2001). Avian Salmonellosis is a significant disease due to its ability to cause not only a clinical illness in poultry, but also can be transmitted to humans through food, thereby acting as a major source of food-borne transmission (Kabir 2010). Avian salmonellosis, due to its infective strains that are lethal to both humans and animals and its ability for zoonotic transmission via food, has made salmonella not only a concern for public health but also a hot topic in several programs of local, national, and international surveillance. Hence, exposure to avian salmonellosis can result in a health risk (Steve et al. 2004). In the USA, more than 40,000 instances of Salmonella infection, along with 400 fatalities resulting from Salmonellosis of acute nature are documented annually (Fabrega and Vila 2013). Non-typhoidal Salmonella (NTS) infections impose a substantial annual economic burden of approximately $11.39 billion on the U.S. economy, surpassing the costs associated with other bacterial food-borne illnesses. This makes NTS the most expensive food-borne pathogen regarding its impact on health outcomes, resulting in losses of around $3.7 billion (Batz et al. 2014). In a nutshell, Salmonella causes a huge economic loss in the poultry industry via mortality and decreased production (Bierschenk et al. 2017).

The "Avian Salmonellosis" chapter depicts the relationship between Salmonella bacteria and avian populations, focusing mainly on birds as reservoirs and vectors responsible for zoonotic transmission. The chapter digs into various aspects of this zoonotic disease, covering its impact on avian health and its potential risks to human populations. This chapter's sole aim is to provide readers with an understanding of avian salmonellosis as a zoonotic threat. By examining the interplay between avian hosts and Salmonella pathogens, this chapter aims to educate readers about the salmonella prevalence, distribution, transmission routes, particularly to humans from avian hosts, and most importantly, strategies for preventing and controlling avian salmonellosis, emphasizing One Health concept. By fulfilling these objectives, the chapter aims to contribute to the broader understanding of zoonotic diseases within the context of the book "Zoonosis."

2. AVIAN SALMONELLOSIS: AN OVERVIEW

Salmonella is a significant zoonotic pathogen that triggers transmissible ailments in animals and human beings (Li et al. 2018). Annually, Salmonella infection not only results in diminished productivity and, in some cases, fatality in avian, but it also leads to the spoilage of the human food supply, resulting in financial setbacks within the poultry sector. Additionally, it poses a vulnerability to public health (Sylejmani et al. 2016). The Salmonella genus is comprised of two genetically distinct species. One of these species, *Salmonella enterica*, can be additionally classified into six subspecies according to biochemical response patterns. Among these subspecies, only one, namely *Salmonella enterica* subspecies *enterica*, is known to be linked with diseases in animals with regulated body temperature, encompassing a vast array of more than 2,500 motile and non-host-adapted serovars, including examples like *Salmonella enterica* subspecies *enterica* serovar *Enteritidis* and *Salmonella enterica* subspecies *enterica* serovar *Typhimurium* (Gast and Porter Jr. 2020). *Salmonella enterica* has the ability to infect various hosts, and it stands as a prevalent culprit behind foodborne illnesses in both humans and a diverse range of animals. Among these animals, food-producing ones, specifically, have been identified as sources for non-typhoidal Salmonella illnesses. Within the realm of poultry, Salmonella infections that are specific to the host lead to systemic diseases, primarily attributed to *Salmonella enterica* serovar *Gallinarum*, which causes fowl typhoid and serovar *Pullorum*, which is responsible for pullorum disease (Chappell et al. 2009), and usually doesn't cause a disease in mammals. On the other hand, Salmonella bacteria that are non-selective for the host coexist within birds and can endure in the alimentary tract. While they typically do not produce noticeable symptoms, they are linked to widespread human illnesses (Dunkley et al. 2009; Gantois et al. 2009).

3. PREVALENCE OF SALMONELLOSIS

The frequency of different serotypes of Salmonella within live birds varies from 6% to 30% (Gutierrez et al. 2009; Liljebjelke et al. 2005; Srinivasan et al. 2014; van de Giessen et al. 2006), and in domesticated birds and their derivatives, it extends from 1% to 65.5% (Antunes et al. 2003; Fearnley et al. 2011; Hue et al. 2011; Hyeon et al. 2011; Jordan et al. 2006; Yang et al. 2011). Adult layers had the highest infection rate i.e.,53.25% in contrast to brooding i.e.,14.55%, developing i.e.,16.10%, and young hen i.e.,16.10% (Rahman et al. 2004). In Mymensingh, 45.9% of layer birds had Salmonella infection (Hossain et al. 1970; Talha et al. 2001). Salmonella contamination in poultry samples has been reported worldwide, with rates of 17% in the USA, 35% in Spain, 36% in Korea, 39% in Brazil, and 53% in Vietnam (Lu et al. 2011; Plym and Wierup 2006). The general occurrence of Salmonella in white layers from commercial settings was 25.55%, with the highest seroprevalence in finisher birds (32.22%), followed by grower birds (26.66%) and starter birds (17.77%). The peak seroprevalence occurred in the wintertime (49.07%), trailed by the fall season (25.71%), summer (18.57%), and then spring (15.38) (Shakir et al. 2021). The first outbreak occurred at the Regional Poultry Farm in Mundayad, Kerala, India, in September 2005. Two grower birds displayed symptoms like drooping, diminished feed consumption, and mortality. The subsequent occurrence likewise transpired in September 2005 at the Central Hatchery in Chengannur, Kerala. There was a significant mortality rate among newly hatched chicks, and some died inside their eggshells. Yellow colonies grown on McConkey agar suggested the presence of *Salmonella sp* (Rajagopal and Mini 2013). A case of classical fowl typhoid was identified in Denmark, affecting 18,000 brown layers housed in battery cages. Epidemiological findings suggested that the introduction of the infection might be linked to the collection of spent hens by a German slaughterhouse (Christensen et al. 1994).

An estimate suggests that Salmonella is accountable for about 93.8 million instances of human gastroenteritis along with 155,000 fatalities on a global scale annually (Majowicz et al. 2010). The top two most common serovars in the US includes: *S. typhimurium* and *S. enteritidis,* and they account for 41.5% of the overall epidemics and makes up nearly 60% of all the Salmonella outbursts globally (Hendriksen et al. 2011) and 91% of incidents in Africa (Uche et al. 2017). NTS was 20.39% in hospitalized patients (Gong et al. 2022). In March 1961, there was a *Salmonella typhimurium* outbreak linked to fresh eggs at a fashionable restaurant in northeast Atlanta. Physicians in North Atlanta noticed numerous patients with severe gastrointestinal symptoms, all of whom had consumed blue cheese dressing at the restaurant. Investigation revealed the dressing was made with a rich, unpasteurized mayonnaise base containing about 22 fresh eggs per gallon, seven times more than usual commercial products. Following the outbreak, the restaurant switched to commercially prepared, pasteurized mayonnaise with lower egg content and pH, preventing further incidents (McCroan et al. 1963).

4. TRANSMISSION AND SPREAD

Salmonella infections are a foremost global public health concern (Sanchez et al. 2002; Tariq et al. 2022). The complex host/reservoir of *Salmonella enterica* (Jajere 2019) presence in the intestines of diverse animals (Joann Colville 2007), acting as reservoirs for potential zoonotic transmission and foodborne illness (Antunes et al. 2016), is facilitated by its broad host range, efficient fecal shedding from carrier hosts, prolonged environmental survival, and effective transmission via various vectors like feed, fomites, and vehicles (Bedi et al. 2022). The transmission sources often involve contaminated poultry, pork, beef, eggs, and dairy products (Acha and Szyfres 2001). Occasionally, foods of plant origin can become contaminated through contact with animal products, human waste, or unclean utensils in commercial processing facilities and household kitchens, leading to incidents of human salmonellosis (Acha and Szyfres 2001).

The heightened risk of zoonotic salmonella transmission to humans through the food chain is attributed to its ability to spread horizontally and vertically within avian communities, occasionally resulting in subclinical infections or remaining completely asymptomatic (Antunes et al. 2016). The primary reservoir for human infections is poultry products, encompassing meat and eggs, frequently sourced from apparently healthy animals (Jibril et al. 2020). Food animals are particularly recognized as a reservoir for non-typhoid Salmonella infections (Revolledo and Ferreira 2012). Recent incidents have underscored the risk associated with raw or undercooked eggs (Humphrey 1994), but broilers are also a significant source of human infection (McGarr et al. 1980).

The primary mode of salmonella transmission involves ingesting contaminated food or direct and indirect exposure to animal feces (Shakespeare 2009). Indirect transmission can occur when individuals come into contact with surfaces or objects where animals reside and move or when they consume food and drinks prepared in environments contaminated with salmonella (Hedican et al. 2010). Even though live poultry infected with Salmonella may seem outwardly healthy, they can sporadically shed the bacteria (Braden 2006). Eggs are particularly susceptible to contamination due to their proximity to chicken feces, and there is a higher likelihood of Salmonella contamination in eggs from hens raised in cage-free systems (Whiley and Ross 2015). Salmonella spp. can be vertically transmitted, passing from parent to offspring or contaminating eggs (Liljebjelke et al. 2005) through the potential contamination of the external eggshell with infected faeces and the infection of the egg's interior before shell formation, encompassing two main routes: horizontal transmission, characterized by potential eggshell contamination through contact with the colonized chicken intestine or exposure to contaminated droppings during or after laying (De Reu et al. 2006) and vertical transmission, which originates from the infection of chicken reproductive organs by *Salmonella enteritidis*, impacting multiple egg components such as the yolk, albumen, eggshell membranes, or the eggshells themselves (Wibisono et al. 2020) as shown in Fig. 1.

Salmonella spp. can quietly inhabit the intestines of poultry and various other animals without causing visible symptoms (Obe et al. 2023). However, when food production practices lack proper hygiene measures, there is a risk of Salmonella spp. contaminating the meat of these animals as it comes into contact with gastrointestinal contents during the slaughter process. A variety of food products, ranging from homemade mayonnaise to omelet mixes, tartar sauce, egg nog, milkshakes, mousse, ice cream, egg sandwiches, scotch eggs, and various other dishes that incorporate either raw or "cooked" eggs, have been associated with instances of infection outbreaks (Hennessy et al. 1996). Infections can result from the consumption of food or water that has been contaminated with bacteria, and the existence of these microorganisms is closely correlated with insufficient hygiene practices (Chlebicz and Slizewska 2018).

Person-to-person transmission is possible when infected individuals fail to follow proper hand hygiene practices after using the restroom and subsequently handling food. Cross-contamination is another concern, especially when clean food items are placed on surfaces that have previously been in contact with contaminated food (Wibisono et al. 2020).

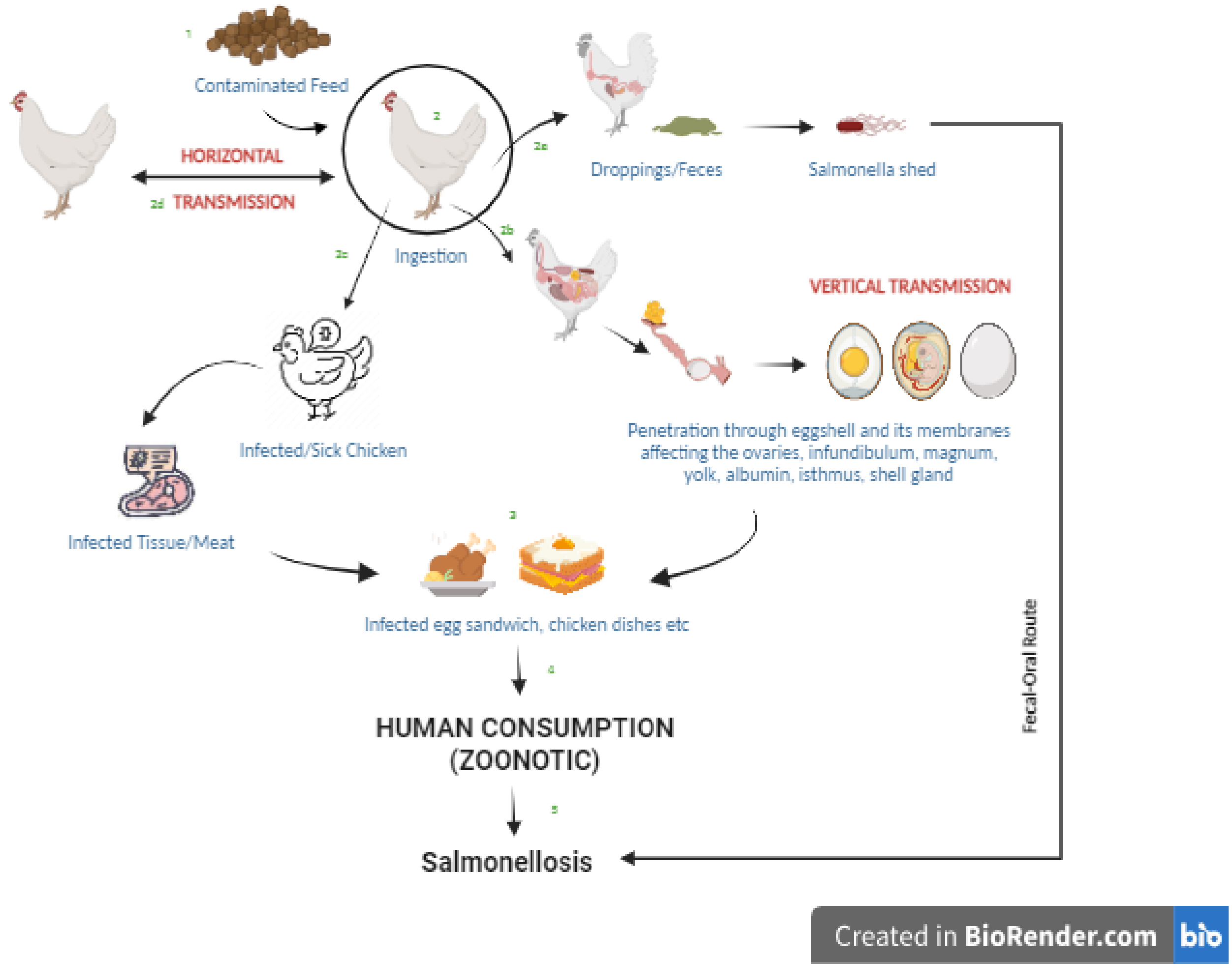

Fig. 1: A schematic diagram showing different modes of transmission of avian salmonellosis as a zoonotic potential to humans: ([1]Healthy bird ingests contaminated feed, [2]represents the initial infection route in avian populations, [2a]Virus shed in droppings which highlights the fecal-oral route as a potential source of human salmonellosis, [2b]Vertical transmission depicting salmonella transmission to eggs and its penetration through eggshell and membranes, affecting various egg components, [2c]Salmnella in poultry meat, [2d]Horizontal transmission depicting transmission through direct contact, [3,4,5]Infected egg and meat products consumed by humans leading to zoonotic transmission of salmonellosis).

Certain animals serve as carriers, intermittently shedding Salmonella. Flies can also play a role in transmitting Salmonella, carrying the bacteria on their feet as they move from contaminated food sources to uncontaminated ones (Thomson et al. 2021). Rodents are potential reservoirs for Salmonella, capable of spreading infections between households and contaminating stored animal feeds. Additionally, insects represent another potential source of Salmonella infection in chickens (Leffer et al. 2010).

5. PUBLIC HEALTH RISKS

Pathogenic bacteria belonging to the Salmonella genus can lead to three distinct forms of salmonellosis in humans: non-invasive and non-typhoid, invasive and non-typhoid, as well as typhoid fever caused by the *S. typhi* serotype, in addition to paratyphoid fever induced by the serotypes *S. paratyphi* A, B, and C (Kurtz et al. 2017). Salmonella infection can occur due to direct contact with infected animals or indirect exposure to their contaminated environments (Chlebicz and Slizewska 2018). When illness does manifest, it typically presents as diarrhea, which may include blood, accompanied by abdominal cramps and fever within a range of 12 to 72 hours after infection (Colville and Berryhill 2007). In the absence of treatment, most individuals will recover within about a week (Colville and Berryhill 2007). A small fraction of those who appear to have recovered from salmonellosis may subsequently develop Reiter syndrome, which affects the joints, eyes, and urogenital tract (Colville and Berryhill 2007). Generally, human beings serve as the primary source of infection, particularly individuals who become carriers following recovery from the disease, as they may continue to excrete Salmonella in their feces and urine for extended periods (Gunn et al. 2014). The infective dose for salmonellosis typically ranges between 10^6 and 10^8 cells (Chlebicz and Slizewska 2018).

Salmonellosis, a frequently encountered zoonotic disease, presents with gastroenteritis marked by a relatively short incubation period (6–48 hours), leading to watery diarrhea persisting for approximately ten days, accompanied by symptoms such as headache, abdominal pain, nausea, vomiting, and fever (Hubálek and Rudolf 2010). In certain instances, the bacteria can infiltrate the bloodstream and lymphatic system, potentially resulting in conditions like meningitis. However, the fatality rate is generally low at around 0.1% (Hubálek and Rudolf 2010), with fatalities primarily occurring in toddlers and elderly patients due to severe dehydration; disease severity tends to escalate in immune compromised individuals, the young, and the elderly, resulting in various clinical symptoms including nausea, abdominal pain, diarrhea, dehydration, and, in some cases, even death (Elliott 2007). Non-typhoidal serotypes of Salmonella, implicated in foodborne outbreaks, also represent a public health concern in addition to their zoonotic significance (El-Saadony et al. 2022). Salmonella infection not only contributes to poultry morbidity and mortality, with *S. gallinarum* causing fowl typhoid and *S. pullorum* responsible for pullorum disease, but it can also spread from diseased poultry to humans (Lillehoj et al. 2000).

Birds, despite consuming Salmonella-contaminated feed without displaying clinical symptoms, can subsequently introduce the bacteria to processing facilities during evisceration, thereby contaminating poultry carcasses and posing health risks to humans (Wibisono et al. 2020). Salmonella spp. rank among the leading bacterial causes of foodborne gastroenteritis (Sanchez et al. 2002).

6. PREVENTIVE MEASURES

6.1. BIOSECURITY MEASURES

Animals serve as the primary source of non-typhoidal salmonellae responsible for human infections. Human exposure to these bacteria primarily occurs through direct contact with animals, handling of animal waste or manure, or indirectly through food contamination with fecal matter, which are the key pathways for human infection (Sanchez et al. 2002). Implementing effective control initiatives involves integrating sound hygiene and management strategies, complemented by routine serological testing and a clearly defined approach to slaughter (Barrow 1993). Crucial management procedures should encompass the introduction of disease-free and healthy chicks into a meticulously cleaned and sanitized environment, guaranteeing the complete removal of *Salmonella gallinarum* and *Salmonella pullorum* while rigorously enforcing biosecurity measures (Gast and Porter Jr. 2020). It is imperative that both the water and feedstuff stay devoid of any contamination caused by Salmonella. Adequate disposal of deceased birds is of utmost importance. Taking thorough precautions to ward off diseases originating from potential mechanical conveyors such as footwear, attire, hatchery equipment, utensils, bedding materials, crates, vehicles, and processing facilities is essential (Christensen et al. 1994). Hazard Analysis Critical Control Point (HACCP) protocols implementation within both the raw material supply chain and the compound feed mill environment can substantially diminish Salmonella contamination risks in both incoming materials and the final feed product. Ensuring consistent and effective control of Salmonella contamination within finished poultry feed hinges on the capability to thoroughly decontaminate the feed and prevent subsequent contamination. For efficient heat-based decontamination, it is imperative to apply a precise combination of specific temperature and duration, along with accurate relative humidity levels, consistently to the finished feed. Equally vital is the safeguarding of the decontaminated feed post-heating to prevent any potential re-contamination, extending these protective measures to the poultry flock. This encompasses the careful management of personnel and equipment access, while employing procedures to maintain the integrity of the hygiene barrier and avoid the introduction of contamination (Totton et al. 2012).

The initiative to manage Salmonella in the poultry sector is a cooperative endeavor that requires the active participation of producers, processors, and consumers, all collaborating to ensure the consumption of safe products (Shariat 2023). Within the pre-harvest environment, Salmonella has the potential to disseminate through diverse transmission routes. These pathways includes the transmission via eggs, inter-bird transfer, exposure to salmonella contaminated water, feed, and litter materials, as well as environmental contact resulting from insufficient biosecurity precautions and pest management techniques (Service 2021). Pre-harvest strategies encompass a range of measures, such as the implementation of robust biosecurity plans, vaccinating breeding stock against Salmonella, utilizing feed ingredients that are free of pathogens, efficient bedding maintenance, and the use of water with added acidity (Ruvalcaba-Gomez et al. 2022). One of the first steps to consider in reducing the presence of pathogens in manufacturing units is the enforcement of good manufacturing practice and sanitation standard operating procedures. It is of utmost importance for facilities to give precedence to the well-being of employees and the cleanliness of the processing area to safeguard both the workforce and the products delivered to consumers (Service 2021). Once a food product enters the food service chain or is purchased by a consumer, it becomes crucial to follow proper handling procedures, ensuring that poultry is cooked to the prescribed internal degrees of heat such as at 165°F (74°C), following the guidelines established by USDA-FSIS, thereby, providing an additional safeguard for consumers (Service 2022) .

6.2. FEEDING STRATEGIES

Antibiotics affect feed efficiency by influencing the gut microbiota, where a competition for nutrients occurs between the host and pathogenic bacteria like *Escherichia coli*, Salmonella species, and *Clostridium perfringens* (Abd El-Hack et al. 2022; Swelum et al. 2021). Due to concerns about antibiotic resistance, the use of antibiotic growth promoters is declining (Danzeisen et al. 2011). *Salmonella enteritidis* being the primary serotype in poultry farming, has developed resistance to several antibiotics (Ray and Bhunia 2007). There's a global effort to reduce antibiotic use and promote organic substitutes for antibiotics, such as prebiotic agents, probiotics, indispensable amino acids, organic acids, essential oils, and more.

Competitive exclusion" occurs when microorganisms in the alimentary canal vie for resources, including nutrients and adhesion points (Nurmi et al. 1992). Disease-causing bacteria like *E. coli* along with Salmonella requires attachment with the enteric mucosal membrane in order to initiate infection in avian (Lan et al. 2005). Lactic acid producing microorganisms, like *Lactobacillus* strains, produce lactic acid through carbohydrate fermentation, diminishing intestinal acidity and inhibiting bacteria like *S. typhimurium* along with *E. coli* and *C. perfringens* (Murry et al. 2004). In vivo studies have confirmed the findings, demonstrating a decrease in Enterobacteriaceae in broiler ceca when levels of acetate, propionate, and butyrate (SCFA's) increased [46]. Incorporating fructo oligosaccharide in daily broiler feed restricts *Salmonella enteritidis* colonization (Shang et al. 2015). Combining probiotics and prebiotics (symbiotics) such as 0.1% of fructo oligosaccharide, reduced Salmonella enteritidis inhabitation in chick intestines more effectively than when used separately (Fukata et al. 1999).

Cymbopogon citratus (extract of lemongrass) demonstrates powerful bactericidal properties towards a range of pathogenic bacteria, including *S. typhimurium* and *S. enterica* (Alagawany et al. 2021). Oregano and Thyme extracted essential oils efficiently reduce Salmonella species establishment in chickens' alimentary `tracts (Koščová et al. 2006).

6.3. VACCINATION

Various vaccines, including bacterins, weakened, subunit, and nanoparticle-founded vaccines, protect birds from Salmonella infections (Fig. 2) (El-Saadony et al. 2022). Inactivated whole bacteria (bacterins) offer variable safety towards salmonella (Davison et al. 1999). Chickens receiving formaldehyde-inactivated *Salmonella Enteritidis* in decomposable microspheres at an age of 2 weeks old showed reduced shedding of salmonella in feces and its colonization in various organs (Liu et al. 2001). Layer herds inoculated with *Salmonella Enteritidis* bacterin vaccines around 14 and 20 weeks showed that Salmonella establishment was absent, unlike the unvaccinated cohort (Davison et al. 1999). Oral administration of an attenuated *S. Enteritidis* vaccine to 9-week-old chickens reduced Salmonella establishment within spleen, liver and in ceca (Cerquetti and Gherardi 2000). Chickens receiving a subunit vaccine at 9 weeks old, followed by two booster doses, exhibited reduced Salmonella colonization in the ceca (Khan et al. 2003). A study by (Salman et al. 2005) involved engineering of vaccine (nanoparticles-based) that is Salmonella-like by attaching *S. enteritidis* flagellin to mimic natural colonization in the gut. These flagellin-coupled nanoparticles effectively prompted specific absorption in the intestinal mucosa, encompassing Peyer's patches. In another study, a Salmonella subunit vaccine was orally administered to layer chickens, having antigenic outer membrane proteins and flagellar proteins of Salmonella within and on exterior of polyanhydride nanoparticles (Fig. 2). This elicited a distinct immune reaction and restricted Salmonella establishment in the intestinal mucosa (Renu et al. 2018).

7. SURVEILLANCE AND MONITORING

In 1885, an American scientist, Daniel E. Salmon, successfully isolated an enteric pathogen discovered in the intestines of pigs (El-Saadony et al. 2022). Over time, various factors such as industrialization, large-scale food production, reduced trade barriers, and increased human migration have contributed to the global dissemination and heightened prevalence of foodborne illnesses (Todd 1997). This development has given rise to significant public health concerns and an increased risk of zoonotic transmission associated with Salmonella, prompting the introduction of numerous surveillance initiatives on international, national, and local scales (Steve et al. 2004). In developing nations, it is estimated that approximately 16 million cases of typhoid fever occur annually, resulting in around 600,000 deaths worldwide (Ivanoff 1995). In contrast, developed countries have largely controlled the transmission of this disease through the practice of good hygiene and sanitation measures, resulting in a decrease in its prevalence (Ahmed et al. 2005). In Pakistan, Salmonellosis is considered endemic, and various studies have been conducted across the country, including Karachi (Hafiz et al. 1993; Saqib and Ahmed 2000), Lahore (Khalil et al. 1993), Peshawar (Gandapur et al. 1993) and Rawalpindi/Islamabad. From 2000 to 2002, in Asia, specifically in Japan, Korea, and Thailand, *S. Enteritidis* was collectively the most commonly reported human serotype, with *S. Weltevreden* ranking second in 2000 and 2001 but dropping to fourth place in 2002, being overtaken by *S. Rissen* and *S. Typhimurium*. In 2002, *S. Enteritidis* constituted 38% of human isolates but only 7% of non-human isolates. Meanwhile, *S. Anatum, S. Rissen, and S. Stanley* were the most prevalent non-human serotypes in Asia (Galanis et al. 2006).

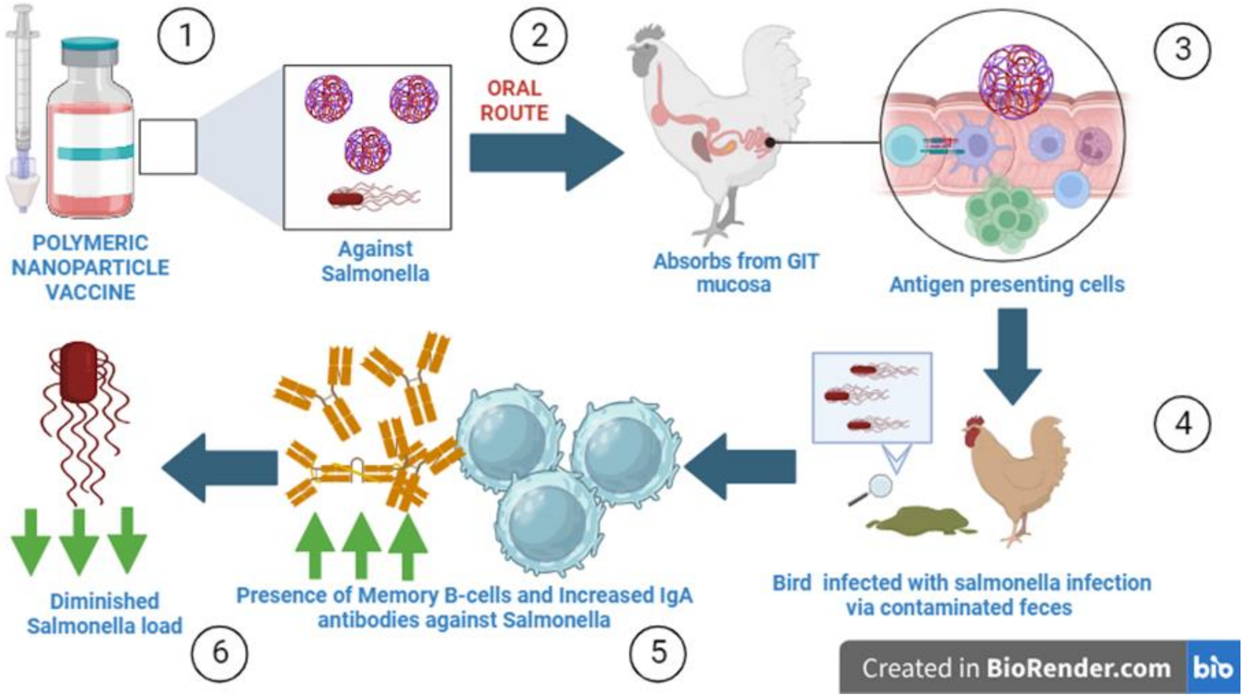

Fig. 2*:* Schematic representation of the defense system of the chicken's body against Salmonella when administered with a polymeric nanoparticle vaccine.[1]Polymeric nanoparticle vaccine is administered to the bird via oral route, [2]The vaccine is absorbed from gastrointestinal tract mucosa, [3]Antigen presentation of vaccine antigen by antigen-presenting cells, [4]Bird infected with salmonella contaminated droppings, [5]Memory B-cells and IgA antibodies are already present in infected chicken's body (virus-neutralization), [6]Decreased salmonella load (Acevedo-Villanueva et al. 2021)

In the United States, there are over 40,000 documented cases of Salmonellosis annually, resulting in approximately 400 deaths each year (Fabrega and Vila 2013). Worldwide, animal products contaminated with Salmonella account for 3% of bacterial foodborne illnesses, causing an estimated 80 million infections and 155,000 fatalities. The literature provides a wide range of estimates for the annual global incidence of salmonellosis, spanning from 200 million to over 1 billion cases (Bierschenk et al. 2017). Effective surveillance programs that can promptly detect and prevent human Salmonella infections require comprehensive monitoring of Salmonella contamination along the entire food supply chain, encompassing animal feed, live animals, slaughterhouses, the retail sector, and restaurants (Newell et al. 2010). In 1997, the United States reported 37,200 confirmed cases of salmonellosis, with 92% of cases based on positive stool samples and 7% from blood samples collected in seven states (Sanchez et al. 2002). The overall incidence of Salmonella infections in the U.S. population in 1998 was 17.4 cases per 100,000 individuals (Sanchez et al. 2002). In the European Union, the number of salmonellosis cases in humans decreased by 5.4% in 2011 compared to 2010 and by 37.9% compared to 2007, indicating a statistically significant declining trend between 2008 and 2011. Salmonellosis is closely linked to poultry production, and substantial efforts are in progress to manage and restrict the spread of this pathogen during various stages of poultry production.

During the summer months, specifically from June to August, approximately 40% of Salmonella infections are reported, with food consumption as the primary associated factor (Sanchez et al. 2002). Children under the age of 1 year are notably susceptible to infection, with an incidence rate exceeding 175 cases per 100,000 individuals. In the age group of 1 to 9 years, the incidence is approximately 50 cases per 100,000 persons, while beyond the age of 9, the incidence decreases to around 25 cases per 100,000 individuals and remains relatively steady across other age groups (Sanchez et al. 2002). Globally, the anticipated fatality rate linked to salmonellosis exceeds 150,000 cases (Chlebicz and Slizewska 2018). Concerning the prevalence of avian salmonellosis based on age, the highest infection rate is observed in adult layers, accounting for 53.25% of cases, in contrast to brooding (14.55%), growing (16.10%), and pullet (16.10%) chickens (Kabir et al. 1970). Worldwide data on Salmonella serotype distribution in humans and various food products have helped establish an epidemiological connection between salmonellosis and poultry items, with diverse serotypes being common to both humans and poultry meat, such as chicken and turkey (Antunes et al. 2016).

8. FUTURE DIRECTIONS AND CHALLENGES

Efforts to combat the rapid spread of antibiotic resistance in poultry should explore alternative control methods like bacteriophages, antimicrobial peptides, and combination antibiotics. Future research focused on development of cost-effective vaccines and innovative delivery methods, particularly automated *in ovo* injection devices, are crucial for Salmonella vaccine development in the broiler industry. Ensuring traceability in poultry-related salmonellosis outbreaks is vital, requiring enhanced record-keeping practices, especially in atcheries and feed stores, to prevent future occurrences and investigate potential alternate transmission routes. Furthermore, addressing Salmonella's animal and public health concerns involves maintaining rigorous management standards, exploring innovative approaches like lytic bacteriophages, and combining established and novel strategies. Poultry breeding companies should focus on researching genetically resistant chicken lines to enhance Salmonella control and identify associated genomic regions for their inclusion in the breeding programs. Contemporary society's shift towards ready-to-eat and takeout foods has reduced home cooking, emphasizing the need for comprehensive collaborative efforts among primary industries, health departments, and food branches to control Salmonella in the egg supply chain, beyond farm-specific strategies. Additionally, public engagement in food safety practices such as post-egg handling handwashing is essential. While numerous national and international regulations should be established to mitigate Salmonella contamination in chicken, significant challenges persist in determining practical and cost-effective control methods within the poultry sector.

9. CONCLUSION

In conclusion, avian salmonellosis represents a noteworthy public health challenge of global significance, characterized by its potential for zoonotic transmission, prevalence in diverse animal populations, particularly poultry species, and association with various food products. These infections, posing risks of gastroenteritis and related health complications, are especially concerning for vulnerable populations, including children. Effectively addressing this issue necessitates the exploration of alternative control strategies, enhancing traceability, and implementing rigorous management standards in collaboration with various stakeholders to ensure food safety and public health protection.

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