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Chicken salmonellosis: An overview on transmission, pathogenesis, detection and control with special reference to its hazard on human health

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Review Article

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Abstract
Globally Salmonella is the most prevalent cause of foodborne disease. Human Salmonella infection is primarily caused by contaminated chicken products. *Salmonella* is an intracellular facultative anaerobic bacillus that can cause localized or systemic infections. In addition to its zoonotic significance, nontyphoidal Salmonella (Paratyphoid illness) present a risk to public health since they can cause food poisoning issues. For many years, the primary method of managing Salmonella was the use of antibiotics, which helped producers enhance the health and growth of animals used to generate food. The use of antibiotics has been reassessed as bacterial pathogens have created and disseminated a variety of antibiotic resistance. Consequently, new techniques to manage Salmonella in the poultry production chain have been developed by the poultry industry which are divided into feeding and non-feeding-based strategies. In this review we tried to articulate definition, transmission, pathogenesis, detection and control of Salmonella species with clarifying its impact on human as a cause of food born disease.

Keywords: *Salmonella, Poultry, pathogenesis, control and Diagnosis.*

Introduction

Salmonellosis is the infection caused by bacteria of the Salmonella type. It is the most famous to be defined as food poisoning, these are described as diseases mainly either toxic or infectious in nature caused by pathogen that enter the body via food ingestion.

The commonest bacteria that cause foodborne illness and mortality is salmonella **Shivaprasad, (2000).** Salmonella is a common foodborne illness that affects the gastrointestinal system and produces cramps, nausea, and diarrhea in people **Jung *et al.* (2022).** Salmonella is a genus of Gram-negative rod-shaped bacteria consists of two species: *Salmonella* enterica and *Salmonella bongori*. The majority of human *Salmonella* infections are caused by *Salmonella enterica subsp. enterica.*

Poultry byproducts (meat and eggs), frequently from healthy animals, are the primary source of infection for humans **Jibril *et al.* (2020).** Human salmonellosis' pathogenicity varies depending on a number of variables, including the strain that caused the infection, the patient's age, and health.

Among animals that produce food, poultry serve as the primary reservoir for several non-typhoidal Salmonella (NTS) serotypes. The NTS serotypes *S. Typhimurium, S. Enteritidis, S. Heidelberg, and S. Newport* are epidemiologically relevant. All ages of birds can contract salmonella, but during the first two weeks of life, young chickens and turkeys are most vulnerable. Poor physical condition, including starvation, frailty, and ruffled feathers, is a hallmark of the illness. Infected birds also have a tendency to cluster together, have diarrhea and a pasty vent, produce fewer eggs. Post-mortem examination revealed enlarged liver and spleen with hemorrhages **Sania *et al.* (2022).**

Nearly 5% of people, encompass immune-compromised people, infants, and older adults, may express bacteremia or invasive infections like meningitis, endovascular infections, osteomyelitis and septic arthritis **Bula-Rudas *et al.* (2015).** Non-specific disseminated infections caused by the typhoidal Salmonella serovars manifest as headache, diarrhea or constipation, loss of appetite, relative bradycardia, and a persistent temperature (39–40◦C).

Since antibiotic residues can contaminate consumed meat, the poultry industry is becoming increasingly concerned about antibiotic replacements due to the rise of multi-drug-resistant bacteria and the related public health concerns **Abd El-Hack *et al.* (2022).** To ensure the safety and cleanliness of chicken products, a variety of preharvest and postharvest techniques have been developed. Farm-level management practices, such as the use of feed additives and biosecurity controls, are examples of preharvest approaches. Slaughter and meat processing activities that apply Hazard Analysis Critical Control Point (HACCP) strategies, are considered post-harvest interventions **Tajkarimi (2007).**

Review methodology

A systematic review of articles published from 1982 to the present was conducted including articles related to the topic regardless of journals and publishers' types. Search terms included were: salmonella, chickens, pathogenesis, diagnosis and prevention.

Genus *Salmonella*

Salmonella is one of the members of Enterobacteriaceae family. They are negative to Gram stain and oxidase test, motile, non-spore producing, rod shaped and facultative anaerobes **Lertworapreecha *et al.* (2013).** Salmonella species are about 2-3 X 0.4-0.6μm in size, Salmonella breaks down D-glucose to produce hydrogen and carbon dioxide, while nitrates are reduced to nitrites, it typically produces hydrogen sulphide **Pui *et al.* (2011).** They negatively react for both urease and indole, Salmonella serotypes grow ideally at temperatures between 35˚C and 40˚C, the cell wall of Salmonella consists of lipids, lipopolysaccharide, proteins and lipoproteins **Cosby *et al.* (2015).** Salmonella as a genus only have two species; *S. enterica* and *S. bongori* with *S. enterica* being the most widely distributed in nature.

Mode of infection and transmission

Severity of infection differs according to several factors like host age, the presence of coinfections, host immunity, environmental stress, managerial factors and infective dose.

Transmission greatly happens via consumption of contaminated egg and meat products **O'Bryan *et al.* (2022).** Poultry infected with Salmonella by different ways like connection with carrier animals as rodents, cats and insects. Contaminated feed, litter, water, and aerosol play role in the transmission of Salmonella **Griffith *et al.* (2019).**

Egg infection with *Salmonella* take place either by horizontal or vertical routes especially by *S. enteritidis*.

Vertical transmission occurs primarily in birds and reptiles where the bacteria from the female reproductive tract transmit to the eggs **Padron (1990).** In horizontal or fecal-oral transmission, eggs infected by eggshell penetration from the colonized gastrointestinal tract (GIT). Feces act as nutrient reservoirs for Salmonela growth, infecting the environment and vigorously contaminating the rest of the flock in the same enclosure. Immaturity a of cuticle with opened pores leads to rapid bacterial penetration of the egg through the first few minutes' post-oviposition **Sparagano (2009).**

Insects play a role of biological vector to *Salmonella Enteritidis* in poultry farms as, Cock-

roaches and poultry mite *(Dermanyssus gallinae).* It is suggested that the primary route of infection could be oral ingestion of crushed infected mites by the chicks, as well as the mite's blood meal **Meerburg and Kijlstra (2007).** Salmonella transmitted by rodents like mice in layer flocks **Bibek *et al.* (2024).** *Salmonella* has the ability to colonize the intestines of wild birds transfering them into asymptomatic reservoirs.

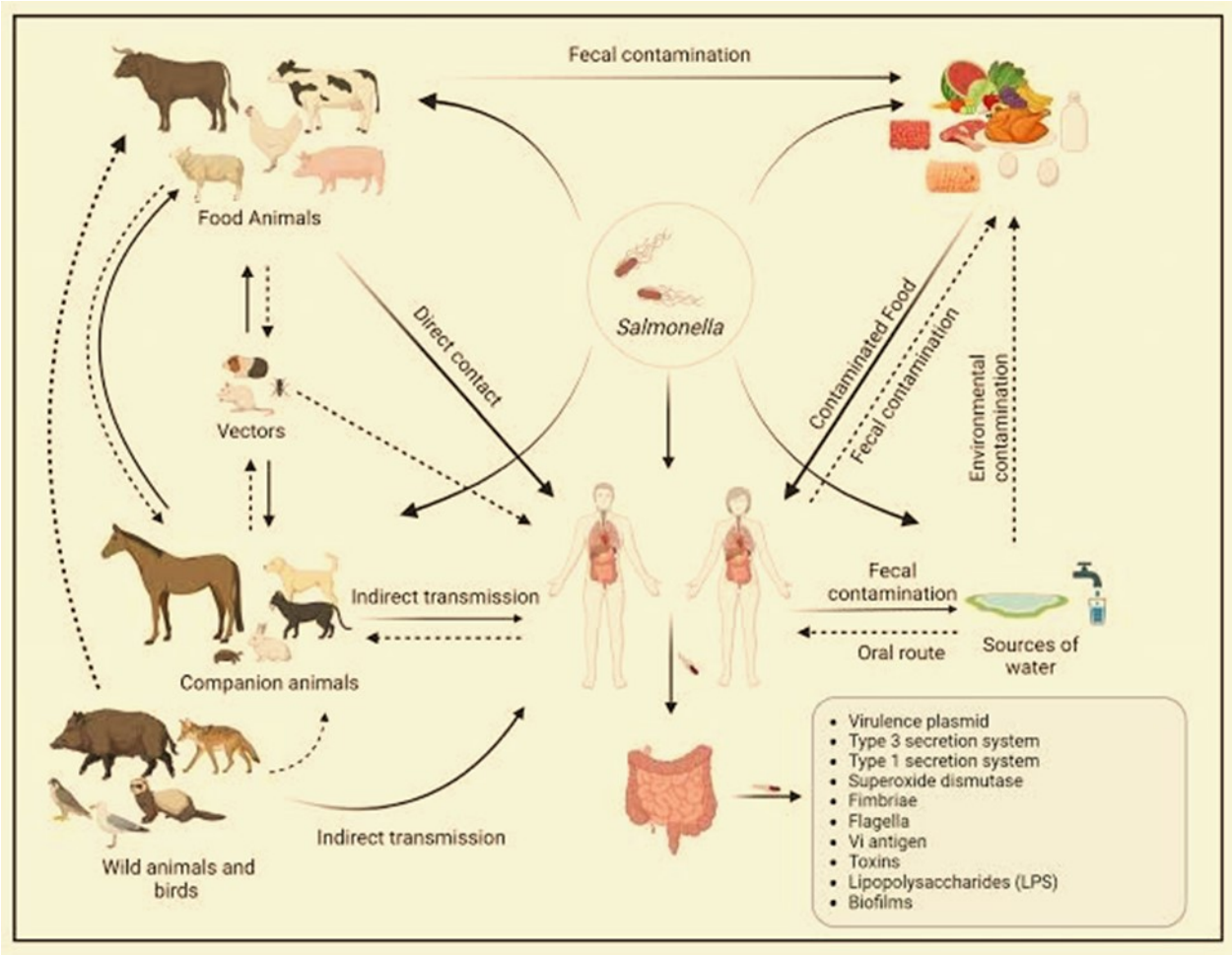

Fig. (1). Salmonella transmission among animals and humans: **Velge *et al.* (2005).**

Salmonella transmitted to human by direct way via ingestion of fecal contaminated food and water or by indirect way by rodents, wild birds and companion animals.

Disease and Clinical signs

Birds are more susceptible to *S. enteritidis* and *S. typhimurium,* which represent the etiology of salmonella infections in humans. Young birds infected with high doses of *S. enteritidis* typically develop clinical salmonellosis **(Medical Microbiology 4 th ed).**

- **Pullorum disease (PD):** Pullorum disease, also named as Bacillary White Diarrhea, is an acute systemic disease of young chicks caused by infection with *S. Pullorum*. Chicks looks huddling under heat sources, making continuous faint chirping and peeping noises. Developing white chalky droppings resulting in white pasted vents (known commonly as 'pasty butt').
- **Fowl typhoid (FT):** An acute or chronic septicemic disease that is occurred mainly in growing and adult chickens and turkeys. The chief eitiology is *S. Gallinarum*. Clinical signs vary according to the severity of the infection. 5-10 days after starting signs of infection chickens will die.
- **Paratyphoid (PT) Infection:** Significantly infect young chicks than adults. It is developed by varied strains of Salmonella spp. Commonly by *S. Typhimurium* and *S. Enteritidis.*

Pathogenesis

Salmonella pathogenesis can be divided into numeral stages, consisting of adhesion and invasion of gut epithelial cells, survival, multiplication within the host cells and extra intestinal spread.

Salmonella find passage via the gastric acid barrier and invade the intestinal epithelium of the small and large intestine by fimbrial adhesins and produce toxins followed by releasing of proinflammatory cytokines which initiate an inflammatory reaction. The acute inflammatory response results in diarrhea and may cause ulceration and destruction of the mucosa. *Salmonella* can disperse from the intestine to cause systemic disease **Buchmeier and Heffron (1991).**

The incubation period for Salmonella is 7 to 14 days. The bacterium's ability to face a pH of 3.7 in the stomach aids the bacteria pass through the acidic stomach environment **Taj-karimi (2007).**

Salmonella can be internalized by macrophages, but they cannot be killed because the germs block phagosomes from fusing with secondary lysosomes, which increases the bacterium's intracellular survival. Within a structure known as the Salmonella-containing vacuole (SCV), Salmonella multiplies in macrophages before being primarily transferred to the draining mesenteric lymph nodes, where it causes bacteremia and invades systemic organs like the liver, spleen, ovary, and gallbladder **Mahari and Gandhi (2021).**

Isolation and Identification of Salmonella

By growth on selective media followed by biochemical and serological testing then classification of genus Salmonella according to Kauffman-White scheme.

Biochemical identification:

Biochemical tests were performed on suspected Salmonella isolates using commercially available media (Oxoid, UK). As presumptive Salmonella, isolates with positive citrate, H2S generation, and motility but a negative indole response was subculture onto nutrient agar (Oxoid, UK) and incubated for the entire night at 37˚C.

Serological identification:

Polyvalent Salmonella antisera (SSI, Denmark) was used in the slide agglutination test to perform serological confirmation on the colonies.

PCR-based identification:

PCR identification using the invA-based approach was performed on isolates that tested positive by serology, which is regarded as a definitive confirmation of Salmonella **Lin *et al.* (2020).**

DNA extraction and WGS analysis

According to the manufacturer's instructions, genomic DNA was extracted using a Promega Maxwell DNA automatic extraction robot and a MaxwellRSC Cultured Cells DNA kit (Maxwell1RSC-16, USA).

Biosensors, a recently developed method for detecting Salmonella in food, offer several benefits over laboratory-based assays, includ-

ing improved sensitivity, accuracy, and specificity as well as low cost, quick response, in situ applications, and portability **Waghamare *et al.* (2018) & Ferone *et al.* (2020).**

Prevention and control

Effective biosecurity and cleanliness are crucial and practical management strategies that are required to successfully lower the incidence of Salmonella during growth out.

I-Management and biosecurity measures:

It is known that Salmonella can infect hens' reproductive organs, depositing the germs into the eggs and perhaps resulting in a chick that is positive for Salmonella **Gast *et al.* (2004).** Therefore, it is best to introduce hatching eggs from breeder flocks that are free of Salmonella **Gast (2007).** Sanitization methods that remove the egg cuticle are not recommended because removal can expose egg pores, allowing an entry point through egg shell penetration **Wang and Slavik (1998).** The presence of fecal particles on the egg's surface could expose it to harmful microbes so, techniques such as UV irradiation of hatching eggs can be used without compromising hatchability **Coufal *et al.* (2003).**

To lessen the hazards of infection flowing in and out of the farm, two types of biosecurity programs can be applied including external and internal biosecurity practices. External biosecurity measures involve the installation of perimeter fences, regulating the movement of vehicles to and from the farm and imposing restrictions on the entrance of animals from external sources **Mannion *et al.* (2007),** whereas internal biosecurity measures include changing footwear and clothing when moving from outside to inside the farm, isolating animals expressing signs from healthy ones, and routinely decontaminate the bedding material and transporting vehicles encompass dead animal transporters **Trampel *et al.* (2014).** The movement of the visitors should be firmly restricted and should be supplied with clean outer clothes and boots.

Decontamination of water, feed and litter are essential as these could be important sources of Salmonella introduction. Chlorine can be used to sanitize the water lines **Poppe (2000).**

Rodents and wild birds can carry the infections from different sources and deliver the infections to other farm animals through their feces on any part of the farm, including food and water therefore, repeated disinfection is required with rodent control **Meerburg and Kijlstra (2007).** For controlling insects, should remove litter and waste rapidly, maintaining the place well-ventilated and dry without any stagnant water **Rebeca and Andrea (2017).** Regular applications of organophosphates and synthetic chemical pesticides are also possible. Natural extracts, such as insecticidal or insect-repelling essential oils and bioinsecticides made of natural ingredients, can be used as a more cost-effective, environmentally friendly, and healthful substitute **Azizi *et al.* (2023).**

◊ **Antibiotic free strategies:**

More "natural" techniques have emerged as the chicken business moves toward lowering or doing away with the use of antibiotics for Salmonella control in poultry because of concerns about the spread of resistant germs in human health **Vandeplas *et al.* (2010)** and concentrated on the feeding- and non-feed-based strategies.

A-Feeding based strategy:

Non-antibiotic alternatives that attentive on application of feeding-based strategies, encompass prebiotics, probiotics, synbiotics, postbiotics and phytobiotics.

A.1. Prebiotic:

The term "prebiotics" describes certain carbohydrates and related substances that are broken down by the host or by the gut-associated microbiota, primarily lactic acid bacteria and bifidobacteria. These include galacto-oligosaccharides (GOS), mannan-oligosaccharides (MOS), and fructo-oligosaccharides (FOS). Therefore, by speeding up the growth of resident beneficial bacteria, prebiotics are typically added to supplements to start a modulatory influence on the gut microbiota **Ricke (2015) & Khan *et al.* (2020) & Ricke *et al.* (2020).** Many authors studied the potential of prebiotics to suppress occurance of Salmonella and decrease its impacts on the poultry gastrointestinal tract.

A.2. Probiotic:

Probiotics, also termed as direct-fed microbial (DFM), are expressed by FAO as “live microorganisms, when supplemented in adequate

amounts, confer a health benefit on the host" **Morelli *et al.* (2012).** Through competitive exclusion, enhanced barrier health and function, immunomodulation, digestion, and absorption, probiotics benefit the host and support development and performance. Spore-forming Bacillus species, Saccharomyces yeast, Enterococcus species, Streptococcus species, Lactobacillus species, and Bifidobacterium species are among the probiotic bacteria used to fortify chicken **Kabir *et al.* (2004).** Scientific studies have mentioned that dietary supplementation based on probiotics can increase productive performance **Rehman *et al.* (2020),** as well as prevent Salmonella infections and reduce their related adverse effects **Khan and Chousalkar (2020).**

A.3. Synbiotics:

A combination of probiotics and prebiotics makes up synbiotics. Because of their mutually beneficial interaction, this approach makes it easier for probiotics to enter the gastrointestinal tract and remain there **Aguilar- Toala *et al.* (2018).**

A.4. Postbiotics:

Postbiotics are metabolic byproducts or non-viable bacterial compounds that are either released by living bacteria or obtained from probiotic microorganisms after cell lysis and have advantageous effects to the host. Generally speaking, postbiotics include SCFA, enzymes, peptides, plasmalogens, organic acids (propionic and 3-phenylacetic acid), vitamins, teichoic acids, and muropeptides. The way that postbiotics work is similar to that of probiotics, but they are not living **Kuralkar and Kuralkar (2021).** Through immunomodulatory effects, lowering gut pH, preventing harmful bacteria in the gut (pathogen antagonism), boosting antioxidant qualities, increasing gut health, preserving the integrity of the intestinal barrier, and boosting production performance, postbiotics help the host.

A.5. Phytobiotics:

Phytobiotics are components or extracts from plants that are used to improve the production and health of a variety of animal species, including poultry. This includes the usage of spices (strongly scented and flavorful herbs) as well as herbs (non-woody, non-persistent plants) **Yildiz *et al.* (2020).** According to reports, phytobiotics may increase feed intake, promote the release of endogenous enzymes, decrease the growth of infections, improve nutrient absorption, increase the quality of the broiler carcass and muscle yield, and strengthen the immune system **Alagawany *et al.* (2021).**

B- Non-Feeding-Based Strategies:

Bacteriophages:

During application of bacteriophages in competing Salmonella: (1) high titer of bacteriophages in single doses more efficient than repeated doses with low titer, (2) application of bacteriophages to inhibit infections is poorly effective due to progression of resistance, (3) potential of bacteriophage treatment rely on the adaptation of the bacteria to release resistance, (4) bacteriophage mix more preferred than single bacteriophages, (5) synergy of bacteriophages with probiotics may accelerate recovery by reducing mortality and spreading of bacteria. The encapsulation strategy overcomes the phage's poor ability to resist the birds' acidic stomach pH when administered orally **Malik (2021).** However, the development of phage resistance is the primary drawback of phage therapy **Luong *et al*. (2020).**

C - In ovo other strategies:

At first, in ovo technique was implemented to upgrade the immune reaction against Marek's disease **Sharma and Burmester (1982) & Bavananthasivam *et al*. (2021).** After that, in ovo injection has been investigated to divide out many types of biological compounds, like probiotics, hormones and immunostimulants. Presenting nutritional solutions in the amniotic fluid of avian embryos was the aim of this procedure. (USA Patent #6,592,878 B2) **Uni and Ferket (2004) & Givisiez *et al.* (2020)** involving various types of nutrients, as carbohydrates (i.e., maltose, glucose), minerals (such as zinc), amino acids, prebiotics (mannan-oligosaccharides, fructo-oligosaccharides), symbiotics, and vitamins (ascorbic acid), among others **Sun *et al.* (2018) & Tavaniello *et al.* (2020),** Improved nutrient absorption, quick jejunum villus development, immune system stimulation, increased expression of enzymes and transporters, increased resistance to pathogens, and early development of the digestive tract and muscle tissues **[Givisiez *et al.***

(2020) & Li *et al.* (2021) these effects may directly or indirectly help control Salmonella infection or lessen its harmful effects.

Conclusion and recommendations

By developing global demand for poultry meat and egg, safe and hygienic poultry management become of great importance to introduce safe food to human. Salmonella transmitted from animals to human across contaminated food and through direct or indirect contact with animal faeces. The unwise usage of antibiotics played a novel role in the enhancement of multi drug resistant so, supplementation of antibiotic alternatives helps in reducing antibiotic resistance besides, effective biosecurity systems that play great role in controlling of Salmonella in poultry farms.

Recommendations

- Apply surveillance programs to monitor the prevalence of Salmonella in the region and identify potential risks.
- Strict hygiene in poultry farms including regular cleaning and disinfection of poultry houses, equipment and feed and water containers.
- Limit access to the farm to essential personnel to prevent introduction of *Salmonella* with rodent and pest control inside the farm.
- Introduce High quality feed that free from Salmonella and store it in a dry, clean and secure place to avoid contamination.
- Introducing Salmonella free breeders is very important and egg should be from negative flock also, hatchery should be cleaned and disinfect properly to limit spread of infection.
- Implementing strict hygienic practice during slaughter and processing with proper chilling of carcasses that help in reducing of Salmonella growth.
- Cost of eradication protocols in case of outbreaks is high, but at last it is more effective and results in better economics.
- Application of antibiotic alternatives together with efficient biosecurity programs to cope antibiotic resistance of Salmonella.
- Use antibiotic wisely in poultry production.
- Human should clean their hands, surfaces, fruits and vegetables effectively and cook foods to the proper internal temperature additionally avoid unpasteurized food (dairy product) and raw or under cooked eggs to keep away from foodborne illness.

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