REVIEW ON SALMONELLOSIS

Kebede Alga, and Asmamaw Aki*

Summary: Salmonellosis is an important disease of chicken all over the world responsible to cause food borne disease in human. It is the leading cause of acute gastro enteritis in several countries and continues to be a major public health concern globally, particularly in developing countries. It is zoonotic disease caused by the genus *Salmonella* which constitutes a major public health burden and represents a significant cost in many countries. The prevalence of *Salmonella* in animals is a continuous threat to human health. Salmonellae are widely distributed in nature and cause a spectrum of diseases in man, animal and birds. Poultry eggs, meat and their products are the commonest vehicles of *Salmonella* to humans. Salmonella is the leading cause of foodborne illness worldwide, with 3.7 billion dollar annual economic loss. It is the leading cause of acute gastro enteritis in several countries and continues to be a major public health concern globally, particularly in developing countries. Although diseases caused by this pathogen have been linked to a wide range of food sources, poultry in particular has been identified as the single most common source of human salmonellosis and appears to be a general reservoir of salmonella. An increase in resistance of Salmonella to one or multiple antimicrobial has been identified in both public health and veterinary sectors in Ethiopia. In this, respect, the majority of the salmonella isolates from poultry farms and poultry products in the previous studies were found to be resistance to several antimicrobials. Therefore, prevention of salmonellosis by the implementation of hygiene measures, and comprehensive control strategy in animals, feed and animal food stuffs will help to reduce salmonellosis and prevention of contamination by cleaning and disinfection, hygiene of personnel and proper processing. Growth of microorganisms in meat and poultry products can be controlled by maintaining a cold chain at 10 ^{oC}, especially for *Salmonella* during transport and storage.

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1. INTRODUCTION

1.1. Background

Salmonellosis is an important zoonotic disease caused by the genus *Salmonella* which constitutes a major public health burden and represents a significant cost in many countries. The prevalence of *Salmonella* in animals is a continuous threat to human health (Jamal *etal.*,2022). Salmonellae are widely distributed in nature and cause a spectrum of diseases in man, animal and birds. Poultry eggs, meat and their products are the commonest vehicles of *Salmonella* to humans (Jajere, 2019). Every year millions of human cases are reported worldwide and the disease results in thousands of deaths (Iwamoto *et al*., 2017).

Members of the genus *Salmonella* are Gram-negative, motile, facultative anaerobic organisms belonging to the family *Enterobacteracae* (Li *et al*.,2021). The genus *Salmonella* contains two species, *Salmonella enterica*, which consists of six subspecies, and *Salmonella bongori.* Currently the genus includes a total of more than 2,500 serotypes (Eng *et al*., 2015). *Salmonella* nomenclature is complex, and is based on names for serotypes in subspecies I. For example, *Salmonella enterica* subsp. *enterica* serotype Enteritidis, is shortened to *S.* Enteritidis (Liljebjelke *et al*; 2017). *Salmonella enterica* subspecies *enterica* (subspecies I) is responsible for 99.5 % of infection in man and animal (Nabil *et al*.,2023). Most of the infections are zoonotic in origin but some serotypes like *S. typhi* and *S. paratyphi* infect only humans (Li et al.,2021). The infectious dose, incubation period, symptoms and mode of transmission of salmonellosis caused by different serotypes are similar. Symptoms include diarrhea, fever and abdominal cramps with incubation periods ranging from 12 to 72 hours. The illness usually lasts from 4 to 7 days and most people recover without treatment. The elderly, infants and those with impaired immune systems are more likely to have a severe illness (Eng *et al*.,2015).

Egg contents may be contaminated with salmonellae by two routes: vertical transmission (transovarian) or horizontal (trans-shell) transmission (CDC, 2022). In transovariantransmission, *Salmonella* are introduced from infected

reproductive tissues to eggs prior to shell formation. *Salmonella* serotypes associated with poultry reproductive tissues and that areof public health concern include *S. enteritidis*, S. *typhimurium* and S. heidelberg (Eng *et a*l.,2015).*S.enteritidis* may be better able to achieve invasion (ACMSF, 2021). Horizontal transmission is usually derived from fecal contamination on the egg shell with penetration after the egg is laid. It also includes contamination through environmental vectors, such as farmers, pets and rodents. Many different serotypes of the genus *Salmonella* may be able to contaminate egg contents by migration through the egg shell and membranes. Such a route is facilitated by moist egg shells, storage at ambient temperature and shell damage (ACMSF, 2021).

Food Standards Agency (FSA, 2018) of the United Kingdom has drawn attention to the riskassociated with eating raw and lightly cooked eggs and issued public health advice on the safehandling and use of eggs. It is estimated that, in the United States,*Salmonella* transmission through contaminated shell eggs or egg products results in 700,000 cases of salmonellosis andcosts 1.1 billion United States dollar annually (USDA, 2023). In many countries, *Salmonella* spp. is controlled in egg production chain. In addition, storing eggs in a cool area (below 15) and keeping eggs separate from other foods is important to avoid possible *Salmonella* cross contamination and keep eggs safe (ACMSF, 2021). One study in Ethiopia showed from the total 400 chicken eggs examined for *Salmonella* prevalence, 46 (11.5 %) were positive, from which 25 (6.3 %) and 27 (6.8 %) were found from egg shell and egg content, respectively (Minte *et al.*, 2011).

The use of antibiotics in food animals selects bacteria which are resistant to antibiotics used inhumans. These might be spread via the food to humans and cause human infection (Salem *et al*.,2023). Amongst *Salmonella* spp., antimicrobial resistance is a well confirmed phenomenonand antimicrobial-resistant *Salmonella* are increasingly associated with the use of antimicrobial agents. Antimicrobials are substances that have significantly contributed to the prevention and treatment of infectious diseases in humans, as well as many animal species (CDC, 2008). However, the excess or overuse of antimicrobials can generate genomic selective pressures to enable microbes to adapt and acquire resistance (Eguale, 2018).

Ultimately, increases in bacterial antimicrobial resistance pose a considerable threat to public health, especially for vulnerable populations including young children (Raji et al.,2021), the elderly and immune compromised individuals (Hitti and Wolff, 2005). Concentrated animal feeding operations (CAFOs) in agricultural practices have evolved to accommodate food consumption rates with increased agricultural output at the risk of introducing antimicrobial resistant pathogens into the environment. In addition, several studies have suggested that characteristics of agricultural environmental settings, including animal crowding, CAFO hygiene, temperature, ventilation control and stress, can influence antimicrobial resistance and pathogen risk (Silbergeld *et al*., 2008; Yasin and Teshager, 2022; Betelhem et al.,2020).

There are reports of high prevalence of resistance in *Salmonella* isolates from countries such as Ethiopia (Ali *et a*l.,2020; Betelhem *et al*.,2020, Ayalu *et al*., 2011; Beyene *et al.,* 2011; Sibhat *et al*., 2011). The presence of resistant organisms in the poultry and poultry products for consumption is a safety concern to the population (Raji et al.,2021) and therapeutic concern for the physicians which might pose prolonged treatment in cases of outbreaks, delayed recovery or treatment failure (Silbergeld, 2008). There is a scarcity of knowledge concerning poultry farm development associated with antimicrobial resistance and foodborne bacteria. Information onthe antimicrobial resistance pattern of the *Salmonella* isolates from chicken table eggs could beuseful for successful treatment, as well as planning strategic use of drugs to minimize resistance in the future.

1.2 **Statement of the Problem**

Salmonella is the leading cause of foodborne illness worldwide, with 3.7 billion dollar annual economic loss. It is the leading cause of acute gastro enteritis in several countries and continues to be amajor public health concern globally, particularly in developing countries. Although diseases caused by this pathogen have been linked to a wide range of food sources, poultry in particular has been identified as the single most common source of human salmonellosis and appears to be a general reservoir of salmonella (Hoque *et al*., 2019).

An increase in resistance of Salmonella to one or multiple antimicrobial has been identified in both public health and veterinary sectors in Ethiopia. In this, respect, the majority of the salmonella isolates from poultry farms and poultry products in the previous studies were found to be resistance to several antimicrobials. The irrational use of first line

drugs and close contact b/n animals and humans have supposed the primary causes for the development of multiple drug resistance which could pose a serious problem in the near future in Ethiopia (Eguale, 2018).

In Ethiopia, the current rates of mortality due to diseases from day old to adult chicken are estimated to be 20-50%. The prevalence of Salmonella in chicken in chicken indicates the potential importance of chickens as source of foodborne salmonellosis (Belege and Aragaw, 2020). According to some of study conducted in different part of Ethiopia, the prevalence rate of poultry salmonellosis were reported 14.6%, 14.6%, 9.27%, 5.5% 24.3%, and 11.5% (Eguale, 2018, Ali *et al*.,2020, Betelhem *et al*.,2020, Abda *et al*.,2021; Belachew *et al*.,2021 and Yasin and Teshager, 2022), respectively. Asmamaw and Gebrehiwote,(2018) reported 23.2% of salmonella from cloacal swab samples in Assosa and Bambasi town, Benishangul-Gumuz Regional State. Human salmonellosis is one of the major diseases in the Ethiopia where, the pooled prevalence of salmonella among human stools were reported as 8.72%, 2.8%, 7.7%, and 3% reported by (Taddesse, 2014, Betelhem *et al*., 2020, Abate and Assefa, 2021, and Melese *et al*., 2022) respectively.

2. LITERATURE REVIEW

2.1. Evolution of Salmonella

The genus *Salmonella* was named after Daniel E. Salmon who first reported the isolation of *Salmonella* from a pig in 1885 and named the organism 'Bacillus Choleraesuis' (currently known as *Salmonella* enterica serovar Choleraesuis). A non-human *Salmonella* spp., *Salmonella* Choleraesius, was isolated from a swine's intestine by Theobald Smith (1859-1934) under the direction of Daniel E. Salmon (1850-1914) in 1885 (Ryan *et al*., 2017). On the basis of biochemical properties and genomic relatedness, the *S.enteric*a is further classified into six subspecies. These subspecies in the nomenclature are denoted by Roman numerals: I.*S. Enteric*a subsp.enterica; II.*S.Enterica subsp.salame*; III.*S.Enterica subsp.arizonae*; IIIa. *S.Enterica subsp.diarizonae*; IV.*S. Enterica subsp.houtenae* and V. *S Enterica Subs indica* (Jajere, 2019).

2.2 Characteristics of the Genus Salmonella

Strain of genus *Salmonella* obey the definition of the family *Enterobacteriaceae*, they are straight rod, usually motile with peritrichous flagella (except *S.* pullorum and gallinarum), facultative anaerobe, ferment glucose usually with production of acid and gas (except *S. typhi* and *dublin*), but failed to ferment lactose, sucrose, salicin and urea, reduce nitrate to nitrite, use citrate as the sole source of carbon, produce H_2S and decarboxylate lysine and ornithine to cadaverine and putrescine respectively (Jajere, 2019; Oludairo *et a*l.,2022).

Salmonellae are small enterobacteria with a diameter around 0.7 to 1.5 μm and length from 2.0 to 5.0 μm (Oludairo *et a*l.,2022). Most Salmonellae form common fimbriae and most of them possess type -1 fimbriae associated with mannose-sensitive adhesive properties which are composed of fimbrillin subunits containing a high proportion of hydrophobic amino acids (Jajere, 2019). *Salmonella* grow optimally at a temperature of 35 to 37 pH about 6.5 - 7.5 and water activity between 0.94 - 0.84. They are chemo-organotrophic organisms (FRI, 2010). The bacteria are sensitive to heat and will not survive a temperature above 70^{o}C; so it is sensitive to pasteurization, but resist to drying even for years. Especially in dried feces, dust and other dry materials such as feed and certain food (Radostitis *et al*., 2007; Jajere, 2019).

2.3 Nomenclature, Serotyping and Classification of the Genus Salmonella

The current nomenclature of the genus *Salmonella* adopted worldwide through different publications is the one used by CDC. It is based on the recommendations from the WHO collaborating centre and it adequately addresses the concern and requirements of clinical and public health microbiologists (Table 1) (Jajere, 2019; CDC, 2021). Scientifically *Salmonella* classification is described under:
Domain: Bacteria
Phylum: Protobacteria
Class: Gamma Protobacteria
Order: Enterobacteriales
Family: *Enterobacteriaceae*

Genus: *Salmonella*, and
Species: *Salmonella enterica* and *Salmonella bongori* (Hafez, 2005; Jajere, 2019). The species *Salmonella enterica* being divided into six subspecies (I – VI); *S. enterica* subsp.*enterica* (I), S. *enteric* subsp. *salamae* (II), *S. enteric* subsp. *arizonae* (IIIa), S. *enterica* subsp.*diarizonae* (IIIb), S. *enterica* subsp. *houtenae* (IV) and *S. enterica*subsp. *indica* (VI) (Jajere, 2019).

Table 1: Currently recognized Salmonella species, subspecies, serotypes and their usual habitats, Kauffmann-White scheme

***Salmonella* species and subspecies**	**Number of sero-vars with in subsp.**	**Usual habitat**
S. enterica :	2557	
S. enterica subsp. *enterica*	1531	Warm blooded animal
S. enterica subsp. *Salamae*	505	Cold blooded animals and environment
S. enterica subsp. *arizonae*	99	Cold blooded animals and environment
S. enterica subsp. *diarizonae*	336	Cold blooded animals and environment
S. enterica subsp. *houtenae*	73	Cold blooded animals and environment
S. enterica subsp. *Indica*	13	Cold blooded animals and environment
S. bongori	22	Cold blooded animals and environment
Total	**2579**	

Source: (Ryan *et a*l.,2017; Gilchrist and Maclennan, 2019).

Salmonella strains are serologically classified using Kauffmann-White scheme, and at the present the genus contains more than 2,500 serotypes (Ryan *et al*.,2017; Gilchrist and Maclennan, 2019). However, a recent report from the Centre for Infectious Disease Research and Policy (CIDRAP) classifies members of the *Salmonella* species into more than 2541 serotypes (serovars) according to their somatic lipopolysaccharide (O), flagellar (H) antigens and at times capsular (Vi) antigen and most strains show diphasic (i.e. they express two flagella antigens variation of the flagellar antigens (CIDRAP, 2006; Scott, 2010). Recently, Diagnostic Services of Manitoba (DSM) suggested the number of *Salmonella* serotypes that causes disease in human now approaches 3000 and new serotypes are identified continuously (DSM, 2009). The majority of the *Salmonella* serotypes belong to *S. enterica* subsp. *Enteric* (about 60 %), followed by subsp. *salamae* (20 %), *diarizonae* (13 %), *arizonae* (3.8 %), *houtenae* (2.8 %) and indica(0.45 %) (Ryan et al.,2017; Gilchrist and Maclennan, 2019).

2.4 Epidemiology of *Salmonella*

The epidemiology of salmonellosis is complex, which often makes the control of the disease difficult. Salmonella spp. is one of the most important food borne pathogens and the third leading cause of human death among diarrheal diseases world wide. The prevalence and diversity of salmonella Enterica serovars in animal based foods (beef, pork poultry, and seafood) throughout the five continents Africa, Americas North, Latin America, Asia. Europe, and Ocean (Ferrari *et al*.,2019). The prevalence of salmonellosis in the different agro ecological areas has shown that this is due to the accessibility and waste disposal as well as hygiene practices of the society (Mengist *et al*., 2018). Poultry and the poultry environment serve as reservoirs for resistance and pathogenic salmonella. However, there was no evidence of transmission along the farm to fork continuum(Melissa *et al*.,2022).

Every year salmonella causes approximately 200 million to over 1 billion infections globally. This includes 93 million cases of gastro enteritis and 155,000 deaths. Shockkingly, 85% of these illness are exclusively related to contaminated food (He *et a*l.,2023). moreover, domestic food poisoning with salmonellosis accounts for 11% of infectious cases in the United States, 35% hospitalization, and 28% death (CDC, 2023). Only five serotypes: *S. Enteritidis;S.*

Typhimurium, *S. Infantis*, *S. Newpor*t and *Salmonella Heidelberg* are responsible for 74% of the 87,923 verified human cases identified in 2019 (EFSA, 2019).

The environment persistence of salmonella is a significant factor in the epidemiology of salmonella in poultry by creating opportunities for horizontal transmission of infection within and between flocks. Salmonella Heidelberg can be isolated from contaminated litter after 7 months of holding at room temperature (Ventola, 2015). Salmonella Typhimurium can survive for 6 months in feed and 18 months in litter stored at 250c. in addition, salmonella can survive for 28 days on the surface of refrigerated vegetables (Huanli *et al*., 2019).

2.4.1 Host range

Salmonella and Salmonellosis occur world wide in mammals, birds, reptiles, amphibians, fish and invertbrates. Majority of salmonella are not host specific and can cause disease in a broad range of hosts but some are host restricted. S. Entrica subsp. Enterica is the most common and predominantly infects warm blooded animals. In the sub species Enterica, serovar Typhi, para typhi and Hirschfeldii are restricted to humans and cause typhoid and para typhoid fever respectively. They have no significant animal or environment reservoirs.serovars S. pullorum and S. Gallinarium are restricted too poultry; S. Abortus ovis to sheep; S. Choleraesuis to pigs and S. Dublin to cattle (Wallis, 2006). The rest of the serovars, referred to as non typhoidal salmonella, are zoonotic or potentially zoonotic, the most common being serovars S.Typhimurium and S. Enteritdis (WHO,2018).

2.4.2 Geographical distribution

Salmonellosis is an avian infectious or clinical disease caused by salmonella and plays an important role in the transmission of food borne disease to humans. Fowl typhoid and pullorum disease are among the diseases caused by salmonella, and they are distributed world wide and have economic significance. These are mainly founded in Latin America, the middle East and the Indian subcontinent, Africa, Southeast Asia, including Bangladesh,India, Pakistan, Nepal and may be other parts of the world. Fowl typhoid infects both commercial poultry and backyard chickens(Kabir, 2010). Another report indicates that pullorum disease has been eradicated from commercial poultry in developed countries such as Western Europe, the USA, Canada and Australia but is still presents in backyard flocks and wild birds. In developing countries,it is still among the major threatening diseases in poultry(Markos and Abdela, 2016). Antibiotics resistance salmonella strains are prevalent in both developed and developing countries and thier emergence is encouraged mainly by the use of antibiotics as growth promoters in food animals and treatments in veterinary medicine (Cui *et a*l.,2021).

2.4.3 Transmission

The primary reservoir for salmonella in animals, particularly poultry is the primary source of food borne human salmonellosis. Transmission occurs mainly through the consumption of contaminated egg and meat products. During the production cycle, poultry can become infected with salmonella through varoius routes,including contact with carrier animals like rodents, cats and insects. Contaminated pouultry feed.litter,water and aerosol transmission also contributes to be the transmission of the salmonella (O'Bryan *et a*l., 2022).

Transmission is horizontal via fecal oral route and vertically via infected eggs. Transovarian infection in the egg results in sub sequent infection in hicks or poults and is one of the most important modes of trans,mission of these two diseases. Some infected hens become asymptomatic carriers and continually transmit to thier progeny. This mode of transmission is particularly critical in hatcheries since it can result in wide spread dissemination of the diseases. Transmission by cannibalism and through the respiratory tract has been reported. Humans constitutes a big potential of the disease introduction via mobility and duties. They can track infection on vehicles, footwear, clothing, hands and contaminated equipment. Mammals, particularly dogs, cats, rodents s well as insects can also act as mechanical transmitters (OIE, 2019; Spickler, 2018).

2.5. Pathogenesis

The clinical manifestation of *Salmonella* infection presents as salmonellosis, an enteric condition which ranges in severity from self-limiting gastroenteritis to septicemia (Shen *et a*l., 2022). The severity of disease depends heavily

on host susceptibility and the virulence of the serovar (CIDRAP, 2006). *Salmonella* asymptomatic carriage is experienced in 5 % of the human population (Zhou *et a*l.,2022).

With association to disease outcome, strains of *Salmonella* are grouped as typhoidal and nontyphoidal organisms (Jajere, 2019; CDC, 2023). An estimated 1.4 million cases per year of gastro enteritis and enteric fever in the United States can be attributed to non-typhi *Salmonella* (CDC, 2024). Infections from specific human pathogens,*S. typhi* and *paratyphi*, resultfrom the ingestion of fecal-contaminated consumables, e.g. food or water and contact with current or chronic carriers of typhoid fever (Miller *et al*., 2000). Typhoid fever is a global health issue of prominent public health concern. Worldwide, typhoid affects over 21.6 million cases with a case-fatality rate ranging from 10-35 % (Crum, 2003; Ehuwa *et al*.,2021).

Salmonella avoid host defense in the stomach and reach the intestines, (CIDRAP, 2006; CDC,2023) and interact with the non-phagocytic cells such as the epithelial cells of the intestinal mucosa (Hensel, 2004). They adhere to the intestinal epithelial cells by adhesive structures (fimbriae) that promote binding and invade epithelial cells to provoke gastroenteritis. The organisms have virulence factors such as virulence-plasmids, toxins, fimbriae and flagella that help in establishing an infection (Shen *et al*.,2022). Pathogenicity is mediated by certain factors such as strain virulence, infectious dose, route of infection and host susceptibility. M cells are the target cells of *Salmonella* pathogenicity (Serpil, 2017). Some of the mechanisms of pathogenesis are bacterial mediated endocytosis, neutrophil recruitment and migration, epithelial cell cytokine secretion, fluid & electrolyte secretion and systemic infection.

2.6 Salmonellosis in Man

With respect to human disease, *Salmonella* serotypes can be divided into three groups that cause distinctive clinical syndromes, typhoid fever, bacteremia and enteritis (Jajere, 2019;). The non-typhoid *Salmonella* serotypes can cause protean manifestations in humans, including acute gastroenteritis, bacteremia and extra intestinal localized infections involving many organs (Mendes *et al*.,2017;Gay *et al*.,2014). Within *Salmonella enterica* subspecies I (*Salmonella enteric* subspecies *enterica*), the most common O-antigen serogroups are A, B, C1, C2, D and E. Strains within these serogroups cause approximately 99 % of *Salmonella* infections in humans and warm-blooded animals. Serotypes in other subspecies are usually isolated from coldblooded animals and the environment but rarely from humans (Velge *et al.*, 2005; Ding *et al*.,2021).

Following ingestion of contaminated food or water, the pathogenesis of both typhoid and *Salmonella* enteritis begins with the intestinal phase, while only typhoid progresses to a systemic phase (Brown *et al.*, 2005). Transmission of this disease within the human population is generally a result of poor sanitation of water and food supplies in developing nations. The broad host-range *Salmonella* serovars are prevalent within warm-blooded animal populations that make up the human food supply and bacterial transmission generally results from consumption of raw or undercooked food products (Spickler, 2018; OIE, 2019).

2.7 Salmonellosis in Animals

Salmonella serotypes have a broad host range (Santos *et al.*, 2003, WHO, 2018) and prevalent in the warm blooded animal population including rodents (Jones, 2005). Reptiles kept as pets, such as turtles, iguanas, other lizards and snakes, are often identified as non-food sources of infection (Hans and Dean, 2006, Wallis, 2006). Some serotypes are highly adapted to animal hosts, such as *S. gallinarum* in poultry and *S.* abortus-ovis in sheep. Many nontyphoidal *Salmonella* strainssuch as *S.* typhimurium and *S.* enteritidis infect a wide range of animal host including poultry, cattle and pigs (Spickler,2013). These serotypes generally cause self limitinggastrointestinal infections usually less severe than enteric fever in humans. However, they alsohave the capacity to produce typhoid-like infections in mice and in humans or asymptomaticintestinal colonization in chickens (Velge *et al.*, 2005).

2.7.1 Salmonella in food animals in Ethiopia

Foods of animal origin, especially poultry and poultry products, including eggs, have been consistently implicated in sporadic cases and outbreaks of human salmonellosis, and chicken products are widely acknowledged to be a significant reservoir for *Salmonella* (Tesfaye *et al*.,2021).

In Ethiopia, there is no *Salmonella* serotype and antimicrobial resistance surveillance and monitoring system, therefore the available information are fragmented and made available through individual publications. One study, conducted on chicken and different chicken products in Ethiopia indicated the presence of different serotypes of *Salmonella* (Molla and Mesfin, 2003; Destaw *et al*.,2020). In that study out of the total 80 *Salmonella* isolates, 8 different serotypes were identified of which *S.* Braenderup was the most frequent followed by *S. typhimurium var. Copenhagen, S. anatum, S. kottbus and S. typhimurium*. Other serotypes isolated include *S. bovismorbificans, S. hadar and S. infantis. S. braenderup, S. anatum* and *S. newport* appear to be the major *Salmonella* serotypes associated with chicken meat and chicken meat products around Addis Ababa (Zewdu, 2008).

2.7.2 *Salmonella* in poultry

The emergence of *Salmonella* in poultry and later in egg production has been related to the industrialization and the globalization of poultry and egg production (Hans and Dean, 2006). Poultry may acquire *Salmonella* from various sources, including birds, feedstuffs, rodents and other vehicles. Clinical disease is uncommon, with the exception of infection caused by the host-adapted serovar Pullorum/Gallinarum, but most infections are of importance as potential sources of food poisoning in man. Poultry products may be contaminated at several stages during the slaughter process, either from faeces during evisceration, or by cross-contamination from contact with contaminated products (Hans and Dean, 2006).

2.7.3 Salmonella in Eggs

Salmonella is a leading cause of food-borne illness in many countries with eggs and poultry being important vehicles of transmission. During the past two decades *S. enteritidis* has become a leading serotype causing human infections, with hen eggs being a principal source of the pathogen (FSA, 2004; Antunes *et al*.,2016).

In United Kingdom, the Department of Health funded a retail survey of UK produced eggs, sampled in England was undertaken between May 1995 and April 1996. *Salmonella* spp. Were detected in 0.99 % of the 13,970 samples of 6 eggs (an estimated contamination rate per individual egg of 1 in every 100 boxes of 6 eggs). There was no significant change in *Salmonella* contamination of UK produced eggs since a previous survey in 1991 (FSA, 2004; Sheffield *et al*.,2014). In another study carried out by the UK Food Standards Agency of A-grade shell eggs on retail sale between March and July 2003, a total of 4,753 samples (mostly boxes) of six eggs were purchased from a cross-section of retail outlets across the UK (Table 2).

Table 2: Prevalence of Salmonella spp. and S. enteritidis in raw shell egg in studies carried out in the UK during 1995–2004.

Year	Eggs from	No. of pooled Sample of eggs	Salmonella isolates	%	*Salmonella enteritidis*	%
1995	UK	13,970	138	0.99	119	0.85
1996-1997	Non UK: EU	1,433	29	2.02	18	1.25
2002	UK, France, Origin not known	726	7	0.96	6	0.83
2003	UK and other EU	5,686	17	0.30	15	0.26
2003	UK	4,753	14	0.30	7	0.14
2002-2004	Germany, Spain, UK, Portugal, USA, Origin not known	2,101	86	4.09	82	3.90

Source: (Little *et al.*, 2007)

Salmonella risk profile of UK- produced hen shell eggs, exposure assessment study of the prevalence of salmonella in laying hen flocks from 2009-2021 reported that, the number of adult laying hen flocks that tested positive for any salmonella was lowest in 2016 at 0.58% (22/3793). There was a peak in 2019 of 1.20% prevalence of any salmonella spp., dropping down to 0.96% in 2021. Since the Advisory committee on the microbiological safety of food (ACMSF) report in 2016, there has been an overall increase in the proportion of regulated serovars and S. enteritidis in laying

flocks. The increase in number of flocks testing positive for S.entritidis in 2019 and 2020 compared to previous years could also be influenced by the occurrence of risk- based enhanced sampling by APHA and BEIC on some premises (APHA, 2021). However, these remain well within the flocks positive target of 2% under the NCP testing regulations. In 2016, 0/3793 NCP eligible laying flocks were positive for regulated serovars including S.entritidis. In 2017, 6/3906 (0.15%) flocks were positive for regulated serovars, all of which were S. enteritidis. In 2018, the proportions reduced, even with an increase in the number of eligible flocks tested, the number of positive for regulated serovars was 4/4106(0.09%). 3 of which were S.entritidis. In 2019, there was a peak where 16/4014(0.40%) were positive for regulated serovars and 14 of these were S.entritidis. In 2020, 14/3959 (0.35%) were positive for regulated serovars and 11 of these were s. entritidis . In 2021 there was a slight reduction in the proportion of testing positive for regulated serovars 9/3977 (0.23%) with 3 of these testing positive for S. entritidis (Table 3).

Table 3. Adult laying flocks tested and positive for Salmonella, 2009-2021(AHVLA, APHA)

Year	Total NCP eligible flock, #adult laying hens	Positive for regulated serovars	Positive fo SE	Positive total , adult
2009	4197	10	7	67
2010	4099	11	6	41
2011	3865	7	5	29
2012	3777	3	1	32
2013	3,687	3	2	37
2015	3674	1	0	22
2016	3793	0	0	22
2017	3906	6	6	28
2018	4106	4	3	26
2019	4014	16	14	48
2020	3959	14	11	42
2021	3977	9	3	38

(Source, FSA, 2023 in UK)

Table 4 . Summary of NCP testing results for laying flocks Brokenn down into two time periods in 2009-2016 by FSA in UK

2009-2016	All tested	All salmonella	Regulated salmonella	S.enteritidis
Flocks	30,796	286	37	23
% of tested	100%	0.93%	0.12%	0.07%

Table 5. Prevalence of Salmonella in laying hen flocks from 2009-2021 by FSA inUK

2017-2021	All tested	All salmonella	Regulated salmonella	S.enteritidis
Flocks	19,962	182	49	37
% of tested	100%	0.91%	0.25%	0.19%

(Source, FSA, 2023)

One recent study in Ethiopia showed from the total of 400 eggs examined for *Salmonella*, 46 (11.5 %) were positive, from which 25 (6.3 %) and 27 (6.8 %) were found from egg shell and egg content, respectively. The isolates of *Salmonella* in egg content of the poultry farm was 21 (10.5 %) out of 200 egg samples and the isolates of *Salmonella* in egg content of open market was 6 (3.0 %) out of 200(7.0 %) and market egg shell was 11 (5.5 %). Similarly, a total of 6 (1.5 %), i.e. 5 (2.5 %) from poultry farm and 1 (0.5 %) from open market were isolated from both egg shell and content eggs (Minte *et al.*, 2011). The *Salmonella* isolates observed from farm egg shell was 14 Bacterial infections of shell eggs and its content such as *Salmonella* spp., especially *S.* enteritidis can occur in two different ways: either vertically or horizontally (EFSA, 2005).

Table 6. Prevalence of Salmonella from shell eggs and egg contents in Ethiopia

Sample place	No. examined	Egg Shell positive (no.(%)	Shell contents Positive

			No.(%)
Bishoftu	28	4 (14.3%	0 (0.00%
modjo	30	5(16.7%	5(16.7%
Akaki	29	4(13.8%	1(3.4%
Dukem	28	1(3.6%	2(7.1%
Total	115	14(12.2%	8(7%)

(Source, Belege T., and Destaw A, 2024)

As the Belege T. and Destaw A., 2024 in Ethiopia, reported that, of the 115 examined eggs, 22(19.1%) were the occurrence of salmonella in egg shell and contents and the prevalence of salmonella in egg shells and contents were 12.2% and 7% respectively.

In vertical transmission, *Salmonella* are introduced from infected reproductive tissues to eggs prior to shell formation. Horizontal transmission is usually derived from fecal contamination on the egg shell. It also includes contamination through environmental vectors, such as farmers, pets and rodents. They may be able to contaminate egg contents by migration through the egg shell and membranes. Such a route is facilitated by moist egg shells, storage at ambient temperature and shell damage by *Salmonella* (FAO/WHO, 2002).

2.8 Contamination Frequency and Infective Dose

Results from sampling eggs from infected flocks will show variability across time in the same flock and between flocks. Variability is expected in any biological system. Seasonal variability in egg culturing results may also be observed (WHO, 2018). In a population of nearly 60 million, about 600,000 persons would eat an infected egg each year, but in most such cases too few bacteria would be present in the egg to constitute an infective dose (Y. Hara.kudo and K. Takatori; 2010).

If a small oral dose of *Salmonella* could commonly infect man, for example, ingestion of less than 10^5organisms, the epidemiology of the infections should resemble that of typhoid fever and bacillary dysentery (Hans and Dean, 2006). Oral infection normally requires the ingestion of large numbers of the *Salmonella* bacteria is afforded by the results of experimental infections. McCullough and Eisele fed different-sized doses of *Salmonella* serovars in egg suspension to adult volunteers. Doses in the range of 10^5- 10^8bacteria were required to cause gastroenteritis, the attack rates being 10-60 % (Y. Hara.kudo and K. Takatori; 2010).

Many recipients of small doses (e.g.,10^4 bacteria) became symptomless intestinal carriers, showing that when a few bacteria escape being killed by the acid in the stomach, the defences of the intestine can restrain their proliferation to a subclinical level. The infectious dose decreases if consumed with liquid food that traverses stomach rapidly or food such as milk and cheese that neutralizes the stomach acid (Y. Hara.kudo and K. Takatori; 2010).

2.9 Health and Economic Impact of Salmonellosis

Salmonella is one of the eight microorganisms in the European Union Zoonoses Monitoring Directive, which shows a disease considered to have a high impact on human health in the Union (Jong and Ekdahl, 2006; kassye *et al*.,2015). Poultry products have always topped the incidence of salmonellosis in many developing countries including India, Egypt, Brazil and Zimbabwe (Henson, 2003; Jajere, 2019) and is the most seriously perceived food risks in chicken meat, even in the developed countries (Dalai *et a*l.,2015). *S.* enteritidis is transmitted to the human food supply through eggs of hens that appear healthy (Porwollik *et al.*, 2005; Yang *et a*l.,2017). Contamination with *Salmonella* in poultry products can occur at multiple steps along the food chain, which includes production, processing, distribution, retail marketing, handling and preparation (Cui *et al.*, 2005; Nidaullah *et al*.,2016).

Salmonellosis, an infection caused by salmonella, is one of the most common and widely distributed foodborne diseases, with tens of millions of humans cases occurring world wide every year (WHO, 2020). In the U.S., there are more than 1.35 million salmonellosis cases each year causing more than 26,500 hospitalizations and 420 deaths (CDC, 2022). A recent study in Australia reported that in 2015, there were nearly, 91,000 non typhoidal salmonellosis cases, of which over4300 were hospitalized and 19 patients died, at a total societal cost of over 100 millions US dollars(Ford *et a*l.,2019).

2.10 Antimicrobial Resistance and Salmonella

2.10.1 Global trends in antimicrobial resistance patterns

Feeds have been responsible for the infection of poultry with multidrug-resistant no typhoid *Salmonella* in several industrialized countries. In food animal production, antimicrobials are administered for therapeutic means, for treatment of infection, prophylactic and non therapeutic purposes for growth promotion and improved feed efficiency (Raji *et al*.,2021). The use of growth promoting agents (GPAs) in feed preparations or water supplements illustrate the largest segment of antibiotic use in poultry production (Mellon *et al.*, 2001; Sodagari *et al*.,2015). The usage of GPAs in food animal production is a major public health threat because this practice can contribute to the emergence of antimicrobial resistance worldwide (Silber geld*et al.*, 2008; Walsh & Fanning, 2008). Chronic, low-level doses of antibiotics and characteristic of GPAs administered in the animal production environment encourage the elimination of susceptible bacteria and yield the selections and expansion of resistant bacterial population (Witte, 2001; Castellanos *et al*.,2018).

Many drugs used in veterinary medicine have identical analogs that are used in human medicine (Smith, 2005; Rodriguez *et a*l.,2015). Animal-derived antimicrobial-resistant bacteria can colonize the intestinal flora of humans. Ultimately, extensive and improper use of antibiotic drugs in food animal agriculture can establish, reservoirs of antimicrobial resistant bacteria, greatly impacting public health (Levy, 2004;Barreto *et al*.,2016).
In developing countries, household subsistence farming is common, which means that a large proportion of the population has close contact with food animals; therefore, if resistant organisms are common in animals, the chance that they will be transmitted to human beings is more likely (Okeke *et al.*, 2005; Sodagari *et al*.,2015).

2.10.2 Resistance patterns in Ethiopia

Antimicrobial resistance is a global problem in general (Munita andArias, 2016), but it might be more severe in Ethiopia where there is lack of antimicrobial resistance assessments of *Salmonella* and lack of rigorous regulations but there is easy access of antimicrobials for purchase of people without prescription and incomplete treatment courses as the result of patient noncompliance (Beyene *et al.*, 2011; Ugboko and De, 2014).

Astudy, Beyene *et al.* (2011) detected multiple drug resistant *Salmonella* organisms in theirstudy on aetiology of febrile and diarrheic illness in Ethiopian children focusing on*Salmonella*. According to Mache (2002; Rodriguez et al., 2015), *Salmonella* was one of the major causes of diarrheain humans. This together with tradition of raw meat consumption and indiscriminate use ofantimicrobials signifies the importance of salmonellosis in the country. In a study conducted by Behailu and Mogessie in 2010, about 70 % of the isolates had varying resistance to the tested antibiotics. Multiple drugresistance was observed in over 30 % of the *Salmonella* isolates. High proportion of *Salmonella* isolates developed resistance to the commonly prescribed antimicrobials and this may be a considerable risk in the treatment of clinical cases (Addis *et al*., 2011). In addition, according to (Sibhat *et al*., 2011) out of the 87 isolates 18 (20.7 %) *Salmonella* serovars consisting of Newport (n = 14), Anatum (n = 3) and Eastbourne (n = 1) were resistant to two or more antimicrobials. Among the antimicrobial resistant *Salmonella* serovars, *S*. Newport was multidrug resistant (15.6 %) and exhibited resistance to streptomycin, sulphisoxazole and tetracycline.

2.11 Prevention and Control of Salmonellosis

Prevention of salmonellosis by the implementation of hygiene measures is difficult and use of antibiotics may give rise to the emergence of resistance problems (Mastroeni and Menager, 2003; Saravanan *et a*l., 2015). Reducing *Salmonella* prevalence requires a multi-hurdle approach at all stages of breeding, hatching, grow-out, transportation and processing. Attenuated DNA recombinant live *Salmonella* vaccines (Renu *et a*l., 2020; Rabie *et al*.,2020), combined with comprehensive control strategy in animals, feed and animal food stuffs will help to reduce salmonellosis. Additional measures to control secondary contamination could be prevention of contamination by cleaning and disinfection, hygiene of personnel and proper processing (Widodo *et al*.,2020). Growth of microorganisms in meat and poultry products can be controlled by maintaining a cold chain at 10 ^{o}C, especially for *Salmonella* during transport and storage (Coleman *et al.*, 2003).

Vaccination does not offer complete protection of the birds against infection. An effective way

to control *Salmonella* in eggs is by preventing the vertical spread of *S. enteritidis* between different generations of birds. The principle is a top down approach, eliminating *Salmonella* from the top of the production pyramid and downwards by test and slaughter (Hans and Dean, 2006; Jia *et al*., 2020). The post-harvest control level of *Salmonella* in infected/contaminated shell eggs can be reduced by decontamination of the surface of the shell by heating, irradiation or other means. Whole eggs should be pasteurized by the process of heating to 60.0 °C (140 °F) for 3.5 minutes. Liquid egg white is pasteurized at 56.7 °C (134 °F) for 3.5 minutes or 55.6 °C (132 °F) for 6.2 minutes. Liquid egg yolk is pasteurized at 61.1 °C (142 °F) for 3.5 minutes or 60.0 °C (140 °F) for 6.2 minutes. In recent years, pasteurized shell eggs have emerged. The process involves pasteurization of the shell egg in water baths for extended periods of time (hours) to achieve a temperature in the center of ~55 °C. Up to a 7-log reduction in *Salmonella* counts in the interior has been documented by this method. Special attention should be given to the preparation and handling of those foodstuffs that have caused a large proportion of outbreaks in recent years, namely mayonnaise, cold desserts and pre-cooked savouries (Hans and Dean, 2006; Jia *et a*l.,2020)

2.9 The status of chicken salmonellosis in Ethiopia

Salmonella is prevalent in broiler, layer, their feed and their environment and most of the isolates are resistance to most antimicrobials used in medical and poultry practices. This has significant implications for public health and antimicrobial resistance (Tesfaye *et al*., 2021). In Ethiopia, the current rates of mortality due to diseases from day oldto adult chicken are estimated to be 20-50%. The prevalence of salmonella in exotic chicken indicates the potential importance of chickens as source of food borne salmonellosis (Destaw et al.,2020). In Ehiopia, many studies were conducted on the chicken salmonellosis prevalence and some of the authors indicated as shown in table 2 below.

Table 7. Prevalence of chicken salmonellosis in Ethiopia in different geographical areas

Study area	Total sample	Type	overall	Author and year
South Ethiopia	270	Cloacal swab	16.7%	Reta *et al*.,2017
Asossa and Bambasi	384	Cloacal swab	23.2%	Asmamaw and gebrehiwote,2018
Central Ethiopia	549	Fecal dropping	14.6	Eguale ,2018
Debre zeit and Modjo	384	Caecal contents	14.6	Ali *et al*.,2020
Adama and Mojo	384	Cloacal swab	2.9%	Betel helm etal.,2020
Kafa zone	302	,,	9.27	Abda *et al*., 2021
Bishoftu and Modjo	539	Feed, water, feedtrough	24.3	Belachew *et al*.,2021
Bishoftu	189	Cloacal swab	26.5	Tesfaye *et al*.,2021
Addis Ababa	200	,,	11.5	Yasin and Teshager 2022

3. CONCLUSION

Salmonellosis is the leading cause of acute gastro enteritis in several countries and continues to be a major public health concern globally, particularly in developing countries. It is an important disease of chicken all over the world responsible to cause food borne disease in human. And it is zoonotic disease caused by the genus *Salmonella* which constitutes a major public health burden and represents a significant cost in many countries. Poultry and eggs are the most important reservoirs from which salmonella is passed into the food chain and ultimately transmitted to humans. Poultry also pass salmonella infections to their embryos vertically through eggs and horizontally to other chicken by contaminated. Therefore, Collaboration among animal health, public health, and the environment through one health approach should be strengthen to minimize the impact salmonellosis in public health and poultry industries, regular antimicrobial susceptibility tests against salmonella should be conducted in order to monitor emergence of new MDR strains, and awareness for farm owners, on chicken management, zoonosis, proper use of antimicrobials and disease prevention and control strategies.

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