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Review on Salmonellosis in Poultry and Its Public Health Importance

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Abstract

Salmonellosis is an important zoonotic disease, which cause a serious illness in animals including birds and humans. The disease is caused by various serotypes of *Salmonella* which are aerobic and faculatative anaerobic, gram-negative rods and motile with the exception of *S.pullorum and S.Gallinarum*.*Salmonella*, like most Enterobacteriaceae, are motile, nonspore forming, reduce nitrates to nitrites, ferment glucose, and are oxidase negative.The genus Salmonellaconsists of only two species, *Salmonella bongori and Salmonella enterica,* with the latter being divided into six subspecies; *S. enterica*subsp. *enterica*, *S. enterica*subsp. *salamae*, *S. enteric* subsp. *arizonae*, *S. enterica*subsp. *diarizonae*, *S. enterica*subsp. *houtenae*, *and S. enterica*subsp. *indica*. It constitutes a major public health burden and represents asignificant cost in many countries. The presence of any serotype of*Salmonella* in food renders that food unfit for human consumption.*Salmonella* are known for its wide range host. It can cause variety ofdiseases in some hosts while in others, can be asymptomatic. Poultry andeggs are considered as major sources for these pathogenic microorganisms. The disease is transmitted from animal to animal, animal to human and human to human direct or indirect pathway. Among *Salmonella* spp. *Salmonella Enterica*is one of the *Salmonella* serotypes responsible for causing enteric disease in humans.

Keywords: Salmonella, public health, poultry, prevention

1. INTRODUCTION

Eggs and egg products are nutritious foods and they form an important partof the human diet. Consuming eggs, however, has been associated withnegative health impacts. Eggs and egg products that are improperly handledcan be a source of food-borne diseases, such as salmonellosis.Salmonellosis is one of the most common and widely distributed food-bornediseases. It constitutes a major public health burden and represents asignificant cost in many countries. Millions of human cases are reportedworld-wide every year and the disease results in thousands of deaths. [11]

Salmonella genus is a member of the Enterobacteriaceae family, comprising Gram-negative rod-shaped non spore-forming bacteria. Their main reservoir is the intestinal tract of humans and animals. [4] Among the different serotypes, *Salmonella enterica*, *S. Enteritidis*,and *S. Typhimurium* account for the most non typhoidal Salmonella infections in both developed and developing countries.[24]These serotypes are regarded as unrestricted, beingable to cause infections in animals as well as in humans. Eggs and egg-based products werefrequently associated with salmonellosis outbreaks caused by *S.Enteritidis* in the United States of America (U.S.A.), as well as in the European Union (E.U). [24] This is a potential consequence of the high frequency at which*S. Enteritidis* colonizes the ovaries of laying hens. Usually this happens without any lesions andfurthermore, when egg storage conditions allow it, this foodbornepathogen may be isolated from the shell egg, as it survives in the forming egg. [28]

A wide range of foods has been implicated in food-borne illness attributable to *Salmonella enterica.* Foods of animal origin, especially poultry, poultryproducts and raw eggs, are often implicated in sporadic cases and outbreaksof human salmonellosis. Recent years have seen increases in salmonellosisassociated with contaminated fruits and vegetables. Other sources ofexposure include water, handling of farm animals and pets, and humanperson-to-person when hand-mouth contact occurs without proper washing of hands. [11]

Human illness by *Salmonella Enteritidis* has increased world-wide in the lasttwo decades, due to ingestion of contaminated eggs, and it is currentlyconsidered the primary cause of salmonellosis in the world.In addition,the presence of *S. Enteritidis* in shell eggs constitutes a public health hazard,and poses a considerable economic impact on the poultry and egg industry.[58]

It is estimated that in the U.S., Salmonellatransmission throughcontaminated shell eggs or egg products results in 700,000 cases ofsalmonellosis and costs $1.1 billion annually.[58]In many countries, *Salmonella* spp**.** are controlled in egg production chain.Egg-laying flocks are monitored for *Salmonella* spp., and any flock confirmedwith *S. Enteritidis* or *S. Typhimurium* is slaughtered. In addition, both feedmaterials and compound feeding stuffs for poultry are tested for Salmonellain those countries. [78]

Despite some attempts to study prevalence of *Salmonella* in Ethiopia, mainly in pig, cattle, poultry meat, minced beef and humans, but the status of the problem in chicken table egg is poorly known. However, studies made elsewhere indicated that chicken eggs are important sources of *Salmonella* particularly among those raw consumers. One study in kombolcha town indicated that Out of the total 400 chicken table eggs examined for bacteriological status of*Salmonella,* an overall 11.5% prevalence of *Salmonella*was found. Therefore, the objective of this review is to review the occurrence of *Salmonella* spp. in eggs and environment and to highlight the public health importance of S*almonella.*

2. THE GENUS SALMONELLA

2.1. Characteristics, taxonomy and nomenclature of Salmonella

Salmonellahave been known to cause illnesses for more than 100 yearswhen it was discovered by Dr. Daniel Salmon.*Salmonella*are Gram-negative bacilli belonging to the Family Enterobacteriaceae. Salmonella, like most Enterobacteriaceae, are motile, non spore forming, and facultative anaerobes that reduce nitrates to nitrites, ferment glucose, and are oxidasenegative.The genus Salmonellaconsists of only two species, *Salmonella bongori and Salmonella enterica,* with the latter being divided into six subspecies (I – VI);*S. enterica*subsp. *enterica*(I), *S. enterica*subsp. *salamae*(II), *S. enteric* subsp. *Arizonae* (IIIa), *S. enteric* subsp. *Diarizonae* (IIIb), *S. enteric* subsp.*houtenae* (IV), *and S. enteric* subsp. *indica* (VI) as shown in Table 1. [54]

Table 1 Nomenclature for Salmonella Enteritidis and associated subspecies,[10]

amily	Genus	Species	Subspecies	Serovar
Enterobacteriaceae	Salmonella	*Enterica*	*Enteric*	*Enteritidis*
			salamae	
			arizonae	
			diarizonae	
			houtenae	
			indica	
		bongori		

Salmonella spp. are bacteria that are widespread in the environment that can be isolated from the intestines of most mammals, reptiles and birds. More than 2,500 serovars of Salmonella have been identified. Further studies have shown that Salmonellais capable of surviving for approximately 87 days in tap water, 115 days in pond water, 120 days in pasture soil and 280 days in garden soil. [62] The key factors identified in Salmonellasurvival time in an external environment were temperature, frost, moisture content, humidity, sunlight,

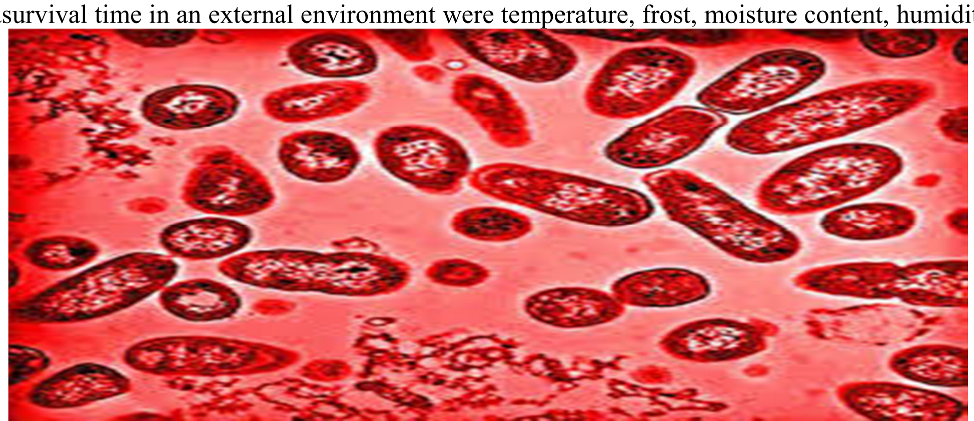

Fig. 1 Sallmonella bacteria, [62]

2.2. Salmonellosis

Salmonellosis is primarily a food-poisoning syndrome, which occurs when ingesting pathogenic Salmonellaserotypes. The cause of food-borne salmonellosis is the penetration and passage of Salmonellaorganism from the gut lumen into the epithelium of the small intestine where inflammation occurs. There is also evidence that the pathogenesis may involve two toxins; an enterotoxin and a cytotoxin.[80]

Salmonellosis is an infectious disease in both humans and animals. The infection is manifested in three forms; gastroenteritis, involving nausea, fever, vomiting and diarrhoea, enteric fever (typhoid and paratyphoid) and septicemia, which is usually characterized by fever, anorexia, anaemia and local lesions on the visceral organs.Human infections are usually associated with animal contact and the consumption of contaminated food products such as poultry, meat and other dairy products.Salmonellosis is usually considered as an asymptomatic or self-limiting illness, but it can also become invasive and fatal, especially for patients who are young or immunocompromized.[80]

Non-typhoidal Salmonella strains are important causes of infections in both humans and animals, and this disease is caused by Salmonellaserotypes other than *S. Typhi* and *S. Paratyphi*. It is a major food-borne infection with worldwide distribution. The majority of cases are self-limiting gastroenteritis.The clinical symptoms usually appear 8 to 72h after contact with the pathogen. The typical symptoms are usually nausea, vomiting, abdominal pain and diarrhea with or without fever. Few (<5%) of the patients develop invasive Salmonellainfections or bacteremia and about 10% of those with invasive disease develop localized infections.During the past decade, there had been a significant world-wide increase of non-typhoidal salmonellosis especially in industrialized countries including, the United Kingdom, Germany, France, Austria, Denmark, and the United States of America. In the U.S.1.3 millions of illnesses and 400 to 600 deaths each year.[42]

2.3. Salmonella in humans

Among*Salmonella* spp. *Salmonella Enterica*is one of the Salmonellaserotypes responsible for causing enteric disease in humans. [12] *Salmonella Enterica* became one of the primary causes for salmonellosis in humans during the late 1970s and early 1980s and continues to be a principal cause in both Europe and North America.[78] SE continues to persist in populations at relatively stable levels. Data collected from 2007 shows that SE was the primary cause, 25.7% of cases, of salmonellosis of human origin in Canada. It has been suggested that for every case presented to a physician 13 to 37 cases actually occur in the population (BCCDC, 2010). [3]

The primary signs and symptoms of salmonellosis in humans are: 1) acute enteritis characterized by fever, diarrhoea that may have blood and/or mucus, vomiting and abdominal cramps, all of which last on average 4-7 days; 2) chronic enteritis with chronic diarrhoea and abdominal pains that last for weeks to months; and 3) septicaemia. Salmonella does not always cause disease, as the host can destroy the pathogen via immune defence systems or expel the pathogen before damage occurs (Ohland Miller, 2001). [50]

Non typhoid salmonellosis is usually recorded as a localized enterocolitis. The incubation phase ranges from five hours to seven days but medical signs regularly begin 12 -36 hours after intake of infected food. Shorter incubation periods are usually related to higher doses of the pathogen or highly at risk people. Medical signs include diarrhea, nausea, abdominal pain, fever, chills, vomiting, prostration, anorexia, headache and malaise may also occur. The disease period is most often two to seven days. Systemic infections sometimes happen and frequently involve the very young, old or the immune-compromised hosts. A few numbers of cases may lead to death. The patients have a large numbers of *Salmonella* spp. at the start of disease. Some of the patients become carriers but others have quality to excrete Salmonella after 3 months. Nontyphoid salmonellosis can cause chronic diseases with localized infections in particular organs, reactive arthritis, neurological and neuromuscular diseases (Wilson *et al*., 2003). [80]

When non-typhoid *Salmonella* spp. causes disease in the gastrointestinal tract they do so by increasing secretions from the intestinal epithelium, invading the intestinal epithelial barrier and recruitment of neutrophils into the intestinal lumen (Ohland Miller, 2001). [50] This then leads to production of pro-inflammatory cytokines which causes an acute inflammatory response and leads to intestinal fluid secretion and diarrhoea. Thermolabile enterotoxins and cytotoxins are also produced, with the enterotoxin enhancing fluid secretion and the cytotoxin blocking protein synthesis in endothelial cells.[70] The exact genetic control mechanisms of *Salmonella* spp. virulence factors are unknown. The increased secretion and presence of toxins leads to the combination of diarrhoea and epithelium damage, which subsequently causes dehydration problems. [70]

In Australia with 210 cases per 100,000 being reported in children under 5 years of age, compared with a total population level of 40 cases per 100,000 (USDA, 2010a). [15] While young children are not as immune competent as adults, it has been suggested this age group is at a higher risk in large part due to "childish" behavior such as eating dirt, sand and soil, which increases the likelihood of exposure to Salmonellaand other pathogens. There is also the possibility that numbers are artificially high compared to the population due to the fact that concerned parents are much more likely to seek medical attention for signs such as diarrhoea, whereas most adults would ignore such signs of illness in themselves. Immunocompromised people are also much more likely to become diseased due to Salmonellaand also to have more severe symptoms due to their inability to fight off the pathogen. [33]

2.4. Salmonella in chickens

A large number of *Salmonella* serotypes have beenassociated with poultry meat and egg products and arecapable of colonizing and infecting live birds. Salmonella contamination has been a persistent problem affectingthe poultry industry in the United States, whichprocesses over 9 billion broiler hatching eggs throughcommercial hatcheries each year (USDA, 2007b). [72] Contaminatedpoultry meat and eggs, particularly whenthe bacterium is present in the egg contents, are importantvehicles of Salmonellainfections. Several factorscan affect the susceptibility of poultry to Salmonellacolonization. [14] These include 1) age of birds; 2) Salmonellaserotype and initial challengedose level; 3) stress, including environmental, transport,and overt or subclinical disease; 4) presence of feedadditives, such as antimicrobials and anticoccidials; 5)survival through low pH of the stomach; 6) competition with gut microflora; 7) presence of a compatible colonizationsite, and 8) host genetic background. There areseveral potential sources of Salmonellacontaminationin an integrated poultry operation. Environmental factorssuch as air, litter and unclean facilities, and vectors,such as insects, humans, and rodents, are responsiblefor Salmonellacontamination in poultry farms. [14]

Chickens can be infected with many different serovars of Salmonella. Some serovars, such as *S. Pullorum*and *S. Gallinarum*, are host specific for chickens, whereas other serovars, such as *S. Typhimurium*, *S. Enteritidis*, and *S. Heidelberg*, are able to infect a widerange of hosts. There are a number of commonly identifiedserotypes of Salmonellaassociated in chickenswith the most common serovars being *S. Enteritidis, S. Kentucky, S. Heidelberg* and *S. Typhimurium* for clinicalisolates and *S. Heidelberg, S. Kentucky, S. Typhimurium, S. Senftenberg,* and *S. Enteritidis* for non-clinical isolates. [18] Since 1997, *S. Heidelberg* has been the most prevalentserovar reported, with a peak in 2000 of just over 50% of all isolates reported being *S. Heidelberg*.In the early to mid-1990s, *S. Enteritidis* was the most frequently reported serotype in the United States, aswell as in Europe. [14]

Salmonella contamination of poultry in pre-harvest environments can usually be traced to production issues that include contaminated poultry feed or pathogen introduction to the facilities via a wide range of carriers including house pets, wild animals as well as insects (Park *et al*., 2008). [52]

Many of these environmental sources have been reviewedextensively elsewhere but poultry feed has been discussed in moredetail than most other sources (Jones, 2011[39]; Ricke*et al.,* 2013a [57]). Thereare several reasons for the extensive focus on poultry feeds as asource of Salmonella. First of all, since one Salmonella organism pergram of feed can colonize in young chicks, low or undetectablenumbers of Salmonella represent a high risk for infection in thesebirds that is further enhanced by the increased feed mixing andincorporation of individual feed ingredients from a multitude ofsources. This becomesof particular concern if breeder flock hatchlings are exposedsince they represent the starting point for all commercial flocks. In addition, Salmonella can linger in feed forextended time periods with reports of bacterial cells remainingviable for several weeks up to 16 months in dry feed stored at 25 ^{0}C. This is further confounded when feeds aretreated with antimicrobials such as organic acids where Salmonellaeither can become acid tolerant or their recovery and/or subsequentenumeration accuracy using conventional plating methods isinfluenced by carryover of antimicrobial compounds into the media (Carrique-Mas *et al*., 2007[8]). Contaminated feed is also regarded as asource of infectious transmission of Salmonella among flocks. This is further accentuatedby the larger numbers of birds housed in confinementresulting in an increase in more birds being infected simultaneouslyvia aerosols and other routes (Park *et al*., 2008). [52]

2.5. Salmonella in table eggs

According to many reports, eggs are the most likely source of Salmonella infections in humans both in outbreaks and in isolated incidences. Eggs may be contaminated externally by feces from hens shedding Salmonella. If the eggs are improperly washed at the egg processing plant, Salmonella is able to persist on the surface and potentially cross-contaminate the liquid portion of the egg when it is cracked for consumption (EFSA, 2010a). [23]

Eggs can be infected by Salmonella via two major routes, vertical andhorizontal. Vertical transmission (transovarian infection) occurs when the egg contents are contaminated with Salmonella during theformation of the egg, before this is covered with the shell. Horizontal transmission includes trans-shell infection of thecontents of the egg during transit through the cloaca or after oviposition and fecal contamination of the external surface of the shell (EFSA, 2005) [22].Vertical transmission is common in host restricted *Salmonella* serovars, such as *S. Gallinarum*and *S. Pullorum*, but has also beendemonstrated in un-restricted Salmonella, suchas *S. Enteritidis*,*S. Typhimurium*and*S. Heidelberg*. Transmission via this route isdirectly related to the affinity of certain serovars for the reproductive tract of the hens (EFSA, 2010a) [23]. Individual Salmonella strains (within andacross serotypes) can show a different ability in colonizing the hen'sreproductive tract. This can be dependboth on genotypic and phenotypiccharacteristics of the strain, which can influence its virulence, ability toevade the hen's immune response and persistence in the reproductive tract (Gantois*et al*., 2009). [28]

Various Salmonella serovars can also be found in the egg contentsfollowing penetration through the eggshell (trans-shell transmission).This ismore likely to happen in the first minutes after oviposition, when the egg's cuticle is immature and offers less protection against thepenetration of bacteria into the eggs. Furthermore the positivetemperature differential (the egg just laid is warmer than theenvironment) creates a negative pressure that aids the entrance ofbacteria inside the egg if there is amoist environment at the shell surface. Trans-shell contamination of the contents is more likely when the shell quality is poorer for older birds or when there arenutritional problems or certain viral infections. Fecal contamination of the eggshell is normallyconsiderably higher than the contamination of contents, and usuallycorrelates with visible eggshell contamination and with the degree ofexcretion of Salmonella in feces. Externallycontaminated eggs represent a risk in theprocessing phase, as they couldcross-contaminate the egg contents or other foodstuffs (Jones*et al*., 2002). [38]

In a recent study conducted in France, 150 eggs were collected fromthe one day production of each of 28 randomly selected Salmonellapositive flocks. Eleven of the 28 flocks (39.3%) had at least one positiveeggshell. Of the total of eggs tested, the prevalence of Salmonella in theeggshells was 1.05% (Chemaly*et* *al.,* 2009)[26].In the egg albumen, Salmonella can growat 20 °C, while it is unable to grow at temperaturesbelow 10 °C. If Salmonellareaches the egg yolk, it can grow rapidly, even at room temperature (25 °C) (Gantois *et al.,* 2009) [28]. The age of the egg represents a further riskfactor, because the yolk releases iron and nutrients over time. The deterioration of the vital line membrane leads to the leakage of thesenutrients into the albumen and attracts the bacteria towards the yolk, therefore easing the growth of Salmonella (Gantois*et al.,* 2009) [28]. Rapid cooling of eggs can be used to reduce the opportunity for bacterial multiplicationbut lower temperatures can enhance the survival of Salmonellaon theshells and lead to condensation associated problems. Itwas shown that condensation can encourage bacterial penetrationof the eggshell, but seems to have a smaller impact on whole eggcontamination but, cooling eggs rapidly can also lead todamage of the egg shells with an increase of cracked eggs (Jones *et al.,* 2002). [38]

Salmonella Enteritidis and eggs

*Salmonella Enteritidis*is the serovar most frequently associated with egg infection (EFSA, 2010a). [23] This is due to two main factors: its unique ability tocolonize the ovary and the oviduct of laying hens long term, and itsspread and persistence in the parental breeder flock population inmost of the world.Despite the high occurrence of SE in laying flocks, the frequency ofegg contamination by SE is normally relatively low and depends onthe level of contamination of the flock and the time of the productionperiod in which the eggs are laid. Eggs produced soon after the flockwas infected with SE, and especially around the onset of lay, are morelikely to become internally contaminated (Cogan and Humphrey, 2003). [18]

Salmonella Enteritidis is typically associated with egg-related outbreaks (EFSA, 2010a) [23] and has not been always the most prevalent serovar in human infections, for example in the UKduring the late 1970s *Salmonella Typhimurium* was predominant, and *S. Agona* was mostcommon before then (Cogan and Humphrey, 2003). In the UK, a sharpincrease of salmonellosis was observed during the 1980s. This waslargely due to an epidemic of SE PT4 that, in the United Kingdom, commenced in1982–1983 and reached its peak in 1993, to start declining only in 1997. In the UK some layer farms subscribe to the British Egg Industry Council that provides a code of practice (Lion Code) on farms' hygiene and welfare standards. Vaccination against Salmonellastarted in layer flocks in 1998 for farms that subscribe to the BEIC LionCode (Cogan and Humphrey, 2003). [18] These typically larger farms produce more than 80% of retail eggsin the UK. Since the introduction of control measures for Salmonella inlayers, such as control of the breeding flocks and vaccination, thenumber of human infections caused by SE, especially PT4, has reduced dramatically (Cogan and Humphrey, 2003). [18]

Salmonella Typhimurium and eggs

Salmonella Typhimurium is often indicated as the prototype un-restricted Salmonella,even though it has a number of distinct sub-types that vary in their degree of host adaptation.Few eggs related outbreaks of salmonellosis caused by ST arereported in humans in the EU (EFSA, 2010a). [18] Experimental studies have suggested that SE and ST can be equal in their potential to colonize the reproductive tract of hensand to infect forming eggs after a high level artificial challenge, however only SE was isolated from eggs after laying. After intravenous infection of hens with ST, all the eggs laid were negative for ST. It was also demonstrated that ST can persist in the egg albumen during egg formation, and that it could resistlysozyme in the albumen better than SE (Gantois*et al*., 2009). [28] During the 1990s ST definitive phage type (DT) 104 spreadworldwide and is now common in the animal population, includingpoultry, of many countries. ST DT104 does notappear to frequently infect laying flocks and even when they are infectedcontamination of eggs or egg handling equipment is very rare. A lowcapability of STDT104 to cause egg contamination, however an increased risk of egg contaminationwasobserved if the henswere infected at point of lay.Certain phage types of ST, such as DT2 and DT99, are host-adaptedto wild birds and infection in laying flocks withthese strains is normally short-lived. ST of wild-bird origin may befound in free-range flocks, or occasionally in enclosed flocks as a resultof feed contamination by bird droppings (during the final stages ofgrowth in the field or during storage) (EFSA, 2010a). [18] Aphasic (not expressing any phase of the H flagellar antigen) ST in eggshas caused a large outbreak in France in 2009 and ST DT8contamination of duck eggs has caused significant prolonged outbreaksof salmonellosis in humans in England (AFSSA, 2009). [1]

3. CONTROL AND PREVENTION

The preventive methods for reducing the risk of Salmonellacontamination of shell eggs and human salmonellosis outbreaks due to their consumption can be either applied as preharvest or as postharvest procedures. Furthermore, they can be either serotype specific or serotype-independent, the latter being considered a more complex approach (Gast, 2007). [30] The environment of the laying hen house can act as reservoir for Salmonella, along with the feed that can be already contaminated as it arrives in the farm (Umali *et al*., 2012). [69]

Due to these various sources of infection for the laying hens, preventive methods are already applied or available at the farm level: flock testing, sanitation and biosecurity; vaccination; passive immunization

(Chalghoumi *et al*., 2009b); [16] the use of natural antimicrobial products such as bacteriophages (Toro *et al*., 2005), [67] protein and fiber sources (Kassaify and Mine, 2005), [43] competitive exclusion flora, probiotics, prebiotics, and organic acids (Chalghoumi *et al*., 2009b), [16] essential oils (Johny *et al*., 2008), [37] and bacteriocins (Dias Paiva *et al*., 2011). [20] For postharvest control of Salmonella in shell eggs, the first approach is to maintain an adequate temperature during storage (Gantois *et al*., 2009). [28] However, different surface decontamination methods are already applied in the U.S.A. and new ones make the subject of continuous research: egg washing (Caudill *et al*., 2010); [9] ultrasounds (Cabeza *et al*., 2011); [5] microwaves (Lakins *et al*., 2008); [46] irradiation (Cabo Verde *et al*., 2004); [6] gas plasma (Ragni *et al*., 2010); [56] ultraviolet light; [58] and pulsed light. [34] Among all these, the ones authorized in the U.S.A. are the shell washing and irradiation. [71]

3.1. Pre-harvest methods for reducing the risk of Salmonellacontamination of shell eggs

Among the different preventive methods used against Salmonellain poultry, genetic selection may be a promising one in reducingthe occurrence of salmonellosis in layers. It has been shown, indeed, that genetic lines of poultry exhibit different resistancelevels against *Salmonella spp*.[28] A genetic correlation between *Salmonella spp*. contaminationlevel in different tissues has been demonstrated. In an investigationconcerning the heritability of resistance trait in poultry demonstrated that the geneticcorrelation (r) between the concentration (log10 CFU/g) of*S. Enteritidis* in the liver and the genital organs was high (0.56). [28]

Considering the systemic phase of infection, the resistance is partly determined by geneticstrains and that, in resistant lines, the microbial load can reachvalues of up to 1000 times lower, in comparison with susceptiblelines. The identification of genes contributing to resistanceagainst this disease may therefore enhance the genetic selectionof the resistant lines. Furthermore,in experimental conditions the crossbreeding betweendifferent selected lines, for lower or higher propensity to carry*Salmonella spp*., resulted in a reduction by half of the maximal percentageof contaminated animals. Nevertheless, they were unableto accelerate the extinction of disease. [55]

3.1.1. Flock management

A series of environmental-related factors may influence the likelihoodand outcome of Salmonellainfections in poultry. These factorsare: litter, dust, mice, flies and the different surfaces from thehen houses or the farm, with which the laying hens may comein contact with.The levels of Salmonellain the litter have been reported toincrease with increasing the water-activity levels and the moisturecontent, mostly due to accidental water leakage. For this, preventive methods are applied,such as maintaining a litter drying environment througha modest and uniformly distributed ventilation rate (100 to150 ft/min) over the litter surface. The addition of hydrated lime to the litter can markedly reduce *Salmonella Enteritidis* recovery in a relatively short time (less than 24 h), due to the increase in pH of up to 12.57 at an addition of 20% of lime. [16]

Salmonella spp. could be isolated as an airborne pathogen, inside the poultry house, and as well in the outside area of the hen house, up to a 40 ft distance (approximately 13 m). [19] Dust could possibly act as avector for *S. Enteritidis* spread from infected hens to healthy ones, through a potential airborne transmission. Rats and mice are considered a reservoir of Salmonella, with ahigh risk of poultry infections. The transmission and shedding patterns of Salmonellain naturally infected wild rats through daily observations and sampling, *S. Enteritidis* was more frequently isolated from the spleen and liverat the end of the study, in comparison to the number of positivecultures from the feces. [69]

One of the factors that can affect the prevalence of Salmonella on premises is the flock size. A potential connection betweenthe high stocking density of laying hens in conventional cagesand the large volume of feces and dust may lead to an increasein the incidence of Salmonellainfections in this particular typeof housing system. In addition, highstocking densities may indirectly interact with Salmonellainfectionsbecause of the caused stress. [35]

3.1.2. Feed withdrawal for molting purposes

Molting induced by feedwithdrawal, a common practice destined to increase egg productivity,has been shown to enhance the risk of vertical transmission of *Salmonella spp.* [32] During the induced molting, due to stress, transientreductions in the number of specific lymphocyte classes appear,which may cause an increased susceptibility to infection. For this reason, new procedures that would avoid feed removalbut retain at the same time the economic benefits. For molting purposes, alfalfa could be used as an alternative,resulting in a reduction of *S. Enteritidis* colonization in experimentally challenged laying hens. Furthermore, in order to decreasethe population of *Salmonella spp*. in the ceca of laying hens duringmolting, a combination of alfalfaand an extract of *Lentinusedodes,* also known as the Shiitake mushroom. [79] The results showed a high decrease, up to2.72 log CFU/g from the initial *Salmonella spp*. counts, suggestingthat this combination might be successfully used as an alternativeto feed removal during molting periods.Feeding laying hens with wheat middlings caused a cessation ofegg production within 3 to 7 days. The comparison of *S. Enteritidis* levels between unmolted group, molted by feed withdrawal group and wheat middlings feeding group resulted in a difference of 3 to5 log more *S. Enteritidis* in the feed withdrawal group. [60]

Whole cottonseed meal (50% of the diet) can also be used wheninducing molting, hens voluntarily reducing their feed intake. Thistype of molting is believed to be equivalent in effectiveness tothe one produced by complete feed withdrawal, and with thesame consequences on the egg safety, by increasing the risk of *S. Enteritidis* contamination. [19]

3.1.3. Foodborne Salmonella spp. contamination of poultry feeds

Poultry feed can become contaminated with foodborne Salmonellaeither during harvesting, processing at the feed mill or storage. Poultry feeds can also become contaminated with salmonella from animal proteins and otheringredients, or even from the dust present in the feed mills.[30] Different protein sources and cereals have been identified ascontaminated with *Salmonella spp*.; peanut meal, sunflower meal,soybean meal, bran meal, barley, corn, sorghum, and wheat. Animal protein and byproducts destined for obtaining proteinmeals for animal feed have always been considered a major sourceof *Salmonella spp*., one cause being the incomplete decontaminationof these ingredients during processing. [48]

Salmonellacontrol principles involve preventing contaminationfrom entering the facility, reducing multiplication within the plantand killing the pathogen. Among the preventive measures to be applied for Salmonellafeed contamination, the most important areobtaining Salmonella-free feed ingredients, controllingthe dust,restricting the flow of the personnel, reduction of fataccumulation, controlling rodents and wild birds and maintainingthe sanitation of the transport vehicles.[41]

For feed degradation,shortening storage time to prevent browning and caking ofthe feed and the supplementation with soybean oil to prevent fat losses would be of first importance, before implementing other prevention methods.[48] In addition, rapid drying is widely used topreserve raw feed ingredients. Considering theaddition of different antimicrobial agents, disinfectants such asacids (mineral acids, short-chain fatty acids), isopropyl alcohol, aldehydes, and trisodium phosphate may reduce the risk of contaminationwith Salmonella*,* through inactivation of this pathogenduring the storage of feed. [48]

Inactivation of Salmonellain feeds may involve pelleting (whichconsists of thermal processing) and/or chemical addition. Thepelleting process consists of 3 major steps: mixing steam with mashfeed (also called conditioning), pressing conditioned feed throughmetal dies (pelleting), and removal of heat and moisture via largevolumes of air (cooling). [39]

3.1.4. Flock testing, sanitation, and biosecurity

Testing is a very important part of the Salmonellacontrol programs.Testing is however controversial as its efficacy may be sometimeslow, due to a continuous reintroduction of many serotypesof Salmonellain the poultry houses andflocks, from environmental sources. Due to the fact that Salmonellafecalshedding is intermittent, testing this kind of samples does not have reliable results. [30] Nevertheless, environmental sampling has proven to be relatively easy to perform and the testing sensitivityis high, when the appropriate method is chosen, [2] although it only indirectly reflects the actual probabilityof the egg contamination. Intensivemonitoring for *S. Enteritidis* through the use of drag-swab samples,when sampling from different locations: floors, nest boxes,egg belts, dropping belts, scrapers, fan blades and dust, is considereda very efficient approach and may lead to a high sensitivity detection of Salmonella.[45] Because many of the Salmonellaserotypes areinvasive, different tissues are often collected and further tested fordetecting infected birds (liver, spleen, ovary, oviduct, testes, yolksac, heart, heart blood, kidney, gall bladder, pancreas, synovia, andeye). In the end, egg culturingcomes as a confirmatory step in many testing plans, but the detectionof Salmonellainside eggs is very difficult due to the lowincidence at which internal contamination occurs and the verylow initial cell densities of salmonella usually found in freshly laid eggs. [30]

When a flock has been tested positive for *S. Enteritidis* presence in the environment and the eggs, the poultry house in which this flock has resided needs to be cleaned and disinfected through 3 steps: the removal of visible manure, dry cleaning in order to remove dust, feathers and old feed and disinfection with spray, aerosols, fumigation or another appropriate disinfection method. Poultry facilities are often subjected to disinfection using chemicalcompounds (especially phenolic and quaternary ammoniumones), following the removal of waste materials and cleaning by high-pressure spraying. [30]

Applying biosecurity measures program, including the limiting ofvisitors on the farm and in poultry houses, maintaining personneland equipment practices that will protect against cross contaminationfrom one poultry house to another, preventing stray poultry, wild birds, cats and other animals from entering the poultry houses,and not allowing employees to keep birds at home, to ensure thatthere is no introduction or transfer of *S. Enteritidis* onto a farm or among poultry houses.[45]

3.1.5. Vaccination

The control of *Salmonella spp*. infection in hen eggs includes variouspreventive measures, among the most frequently used being vaccination.[74]Active immunization is achieved by inoculation with microbialpathogens that induce immunity but do not cause disease, or withantigenic components extracted from the pathogens. When it issuccessful, a subsequent exposure to the pathogenic agent elicitsan intensified immune response that will eliminate the pathogenor will prevent the disease mediated by its products. Many of the common vaccines currently used at acommercial level in poultry consist of inactivated (killed) or live,but attenuated, *Salmonella spp*. strains. Live vaccines generally conferbetter protection than inactivated ones, the former stimulating both cell-mediated and humoral immunities.[74]

3.1.6. Passive immunization

Laying hens immunized with antigens from selected microorganisms (for example, *S. Enteritidis* and *S. Typhimurium*) reactby producing high quantities of specific antibodies (IgY) which are transported from the blood into the egg yolk. These eggs containinghigh levels of antigen-specific IgY, called hyper immune eggs, can be administered as a feed additive (usually in the formof whole yolk powder) to other species to provide them with passiveimmunity. Moreover, they demonstratedthat these specific antibodies havea growth inhibitory effect on *Salmonella spp*., in a concentrationdependentmanner. They also assessed the ability of preventingadhesion of *Salmonellaspp*. to intestinal cells by using human epithelial Caco-2 cell lines. The results demonstrated that specific IgY was able to reduce the decrease in trans epithelial electrical resistance of the infected Caco-2 cell monolayers, blocking adhesionof *Salmonella* spp. in a concentration-dependent manner. [16]

3.1.7. Natural antimicrobial products Bacteriophages

Bacteriophages are bacterial viruses with theability of using the bacterial cell to multiply. Using a combination of 3 different Salmonella-specific bacteriophagesto reduce *S. Enteritidis* colonization in the ceca of layinghens resulted in a significant reduction of the incidence, up to 80%.Tailspike protein of bacteriophages is a component of the tailapparatus with the role of mediating the specific recognition of itsbacterial host by binding to its surface structures. After oral administrationto 1-day-old chickens, it resulted in a significantdelay of *Salmonella spp*. growth and colonization and a significantreduction of *Salmonella spp*. counts at the level of the ceca, liver, and spleen, in comparison with control groups.[77]

Generally regarded as safe, bacteriophages are considered ahighly efficient tool for the bio control of pathogens in food products. [29] Phage therapy can be successfullyapplied to reduce the *S. Enteritidis* level on poultry carcasses afterslaughter.

Protein and fiber sources

Non immunized egg yolk powder could suppress thecolonization of *S. Typhimurium* in laying hens. After 2 wks of feeding egg yolk powder at a doseof 10.0% in infected laying hens, Salmonellawas completely undetected. At a concentration as low as 5% (wt/wt) in the feed, non immunized egg yolk powder eliminated *S. Enteritidis* at the intestinal level after the 1st week, demonstrated by the negativeresults obtained for the tested fecal samples.This may be explained by the presence of components such as high-density lipoproteins and their derivatives.[44]

3.1.8. Competitive exclusion flora, probiotics, prebiotics, and organic acids

The use of competitive exclusion flora, probiotics, prebiotics, as well as acid-based products have been widely investigatedworldwide as preventive methods for *Salmonella* spp. colonizationin poultry.Competitive exclusion products involve the introduction of intestinalbacteria from mature healthy poultry to newly hatchedchickens, the concept being defined as “the early establishmentof an adult intestinal microflora to prevent subsequent colonization by enteropathogens.” The mechanism used by the bacterialspecies from the competitive exclusion products to inhibit theproliferation of other bacteria consists of creation of a restrictivephysiological environment (for example, bacteriostatic effect of Volatile fatty acidin the ceca). [75]

The potential mechanismsthat allow the exclusion of pathogenic species, among them*S. Enteritidis*, by the probiotics include competition for adhesionsites and nutrients or production of antimicrobial compounds, such as bacteriocins, VFA, or hydrogen peroxide. Besides the inhibition of cecal colonization by pathogens, it has been demonstrated that probioticbacteria determined an increase of the oxidative burst capacity and degranulation of heterophils isolated from chicks 24 h afterprobiotic administration. This suggests a possible activation of theinnate immune system. [25] It has been suggested that lactobacilli isolated from either cloaca or vagina oflaying hens present in vitroinhibitory activity against *S. Enteritidis*, with no differences noticed between those isolated from the cloacaand the ones from the vagina. Lactobacilliisolated from the cloaca and the vagina of laying hens inhibitedSalmonella growth *in vitro*and decreased *S. Enteritidis* colonization *in vivo*. Salmonellainhibition was shown to depend on the speciesof Lactobacillus, correlated to some extent with the production of lactic acid of each.[25]Another probiotic with potential use in laying hens is based onan active ingredient consisting of *Bacillus cereus* var. *toyoi*spores. Its efficacy against *S. Enteritidis* has been demonstrated on poultry. [76]

Another option as a preventive method is the use of pre-biotics. They can be regarded as an integrated approach to an improvementof food safety, starting with the maintenance of a healthy intestinalecosystem. [27]Among the beneficial effects of prebiotics these can be mentioned: stimulation of the immunesystem, reduction of inflammatory reactions, toxin inactivation, modification of the intestinal microbiota, increased production of VFA, and prevention of pathogen colonization. [59] Prebiotics are not digested or metabolized, or they are metabolizedvery little, during their passage through the upper portionof the gastrointestinal tract (GIT).

Therefore, they enter thececa without any change to structure, being fermented by thecolonic flora. Through the stimulation of bifido bacteria, they may have the ability to inhibit pathogenic bacteria such as *Salmonellaspp*. It is also possible to decrease egg contamination risk by addingorganic acids to the feed or drinking water at an appropriatetime. [63] Butyric acid is the most frequently used organic acid as a feedor drinking water additive.

3.2. Postharvest methods for reducing the risk of salmonellosis due to contaminated shell eggs consumption

3.2.1. Shell eggs storage and prevention of growth and multiplication of Salmonella

Prompt refrigeration to temperatures capable of restricting microbialgrowth has been recommended as an approach to reducingthe likelihood that contaminated eggs will transmit *S. Enteritidis* to humans. Research in this field has proved that ambient temperatures arenot proper for the storage of shell eggs, especially since the riskof *S. Enteritidis* horizontal transmission has increased, and furtheron, due to its capacity of growth and multiplication inside the shelleggs. The temperaturevalues for shell eggs storage should not exceed 20 ^{0}C. In eggalbumen, *Salmonella spp*. can grow at 20 ^{0}C, while unable to growat temperatures below10 ^{0}C, therefore showing that a temperaturevalue for optimal storage of eggs should not exceed this last value. [28]

3.2.2. Egg washing

Egg washing procedure uses water or solutions that involvechemicals (sanitizers) to determine an efficient decontamination.It is believed that different chemicals used to decontaminate theeggshell may interact with its physical barrier components.

The main advantages of egg washing procedure are: the reduction of microbial load on the shell surface, minimizing the risk associated with the presence of foodborne pathogens, especially *Salmonella spp*., further reduction occurring after washing, since different chemicals may still be present after the washing step, continuing to exert their antibacterial effect, reduced risk of cross-contamination of other foods and reduced risk of contamination of the egg content, provided that the shell itself is not damaged. The main disadvantage comes from the potential damage thatthis practice can cause to the physical barrier of the egg, especially to the cuticle. [22]

3.2.3. Electrolyzed water

Electrolyzed oxidizing water (EOW) is produced by passing a diluted salt solution through an electrolyticcell, within which the anode and cathode are separatedby a membrane, obtaining an acidic and an alkaline component. Acidic EOW is effective in reducing the populations ofpathogenic microorganisms on the surface of shell eggs (aimingat *S. Enteritidis*), but its use is limited when low pH values areobserved (less than 2.7), because dissolved Cl_2 gas can be rapidly lost dueto volatilization, decreasing the bactericidal activity of the solution with time.[7]

3.2.4. Microwave technology

Microwaves are oscillating electromagneticwaves with frequencies in the 300 MHz to 300 GHzrange.The effects of microwaves on pathogens can be generally expressedin 2 forms: thermal and non-thermal. Thermal inactivationis caused by heating during the microwave application process, involvingchanges such as denaturation of enzymes, proteins, nucleicacids or other vital components aswell as disruption of membranes.[47]

Non thermal effects have been classified in 4 categories: Selective heating, explained by the fact that microwaves heat solid microorganisms more effectively than by the surrounding medium, causing a more rapid killing of the organism, Electroporation, caused when an electrical potential crosses the membrane of the microorganism, determining the formation of pores in the membrane, and a further leakage of cellular components, Cell membrane rupture, due to the voltage drop across a membrane and Magnetic field coupling, caused by a disruption in internal components of the cell, leading further on to cell lysis.[47]

3.2.5. Ultraviolet light technology

Ultraviolet (UV) light is lethal to most microorganisms.Among its practical applications may be mentioned: inhibitionof microorganisms on surfaces, destruction of microorganisms inthe air and sterilization of liquids. UVradiation inactivates microorganisms by inducing a cross-linkingbetween pyrimidine nucleotide bases in the DNA, this resultingin inhibition of DNA transcription and replication mechanisms,leading eventually to microbial cell death. In addition, it has beendemonstrated that UV radiation affects cell membrane integrity, inducing protein modifications and inhibiting oxidative phosphorylation.[58]

3.2.6. Ultrasounds

Ultrasound treatment of food products is a usefultool to minimal processing, due to the fact that the transfer ofacoustic energy is instantaneous and distributed throughout thewhole volume of the products. [68] The mechanism of microbial killing by ultrasonic waves is mainly dueto the thinning of cell membranes, localized heating and productionof free radicals. Micro-mechanicalshock waves are created by making and breaking microscopicbubbles induced by fluctuating pressures under the ultrasonication process; these shock waves disrupt cellular structural andfunctional components and lead to cell lysis. [68]

3.2.7. The use of plant extracts

The consumers' demand for organic and non processed food products is increasing; therefore the use ofplant extracts for table eggs decontamination may be considered asuitable option, from this point of view. The phenolic compounds are responsiblefor their bactericidal effects as they interact by permeabilizing the membrane. Their biological activity seems to depend also onthe solvent used for extraction. A natural herb extract that has an inhibitory effect onSalmonellaand other harmful bacteria. [43]

4. Salmonellosis and public health

Growth in international trade and current facilities for traveling increased not only thedissemination of pathogenic agents and contaminants in foodstuffs, but also ourvulnerability. Nowadays, the world is interrelated and interdependent. Thus, localfoodborne disease outbreaks have become a potential threat for the whole world.Globalization, commercialization and distribution make it possible for a contaminatedfoodstuff to affect the health of people in several countries at the same time. Theidentification of only one contaminated food ingredient may lead to the discard of literallytons of food; to considerable economic losses to the production sector; restrictions to trade; and effects on the tourism industry.Therefore, there is an ever growing perception of the need and importance for surveillancesystems and adoption of measures to ensure food safety, such as the identification of the foods involved in food borne disease outbreaks.[65]

Salmonella is an intestinal bacterium responsible for severe foodborne intoxications. It isone of the most important agents involved in outbreaks reported in several countries. Salmonellosis is an important socioeconomic problem in several countries, mainly in developing countries, where this etiological agent is reported as the mainresponsible for foodborne disease outbreaks. It is one of the most problematic zoonosis interms of public health all over the world because of the high endemicity, but mainly because of the difficulty in controlling it and the significant morbidity and mortality rates. [66]

The CDC regularlyreports Salmonella outbreaks that are associated with poultry and poultry products, [12] and these food products are generallyrecognized as a primary source of salmonellosis. Poultry andeggs are considered one of the most important reservoirs fromwhich Salmonella is passed through the food chain and ultimatelytransmitted to humans. With increasing consumption of poultry andpoultry products, the number of salmonellosis associated withpoultry continues to be a public health issue in the US. Since Salmonella is a major causative agent for poultry-associated foodborneillnesses, improving safety of poultry products by earlydetection of foodborne pathogens would be considered an importantcomponent for limiting exposure to Salmonella contamination.This monitoring of poultry and other related products for Salmonellacontamination could be made significantly more effective byemploying rapid and sensitive detection systems. Transmission of Salmonella to humans typically occurs when ingesting foods thatare directly contaminated by animal feces or cross-contaminated by other sources. [49]

Historically, *Salmonella Typhimurium* was the most common agent of the foodborne diseasein humans, although in the past decades *Salmonella Enteritidis* has been most frequentlyinvolved in salmonellosis outbreaks.There is a growing concern about human infections caused by other serovars, such as Infantis, Agona, Hadar, Heidelberg and Virchow.[26]

Concerns about the presence of *Salmonella spp*. in foodstuffs of poultry origin increased inthe 1980s, when *Salmonella Enteritidis* phagotype 4 was responsible for several outbreaks offoodborne disease in England, caused by the ingestion of foods containing poultryingredients. The vertical transmission of *Salmonella Enteritidis* in commercial poultry was responsible for the increased number of cases ofhuman infection in Europe, North America and other parts of the world. Thesespecies replaced *Salmonella Typhimurium*, which was the most common agent of humanfoodborne infection until the 1980s. [51]

According to the National Health Surveillance Agency in Brazil (ANVISA), among the etiological agents of food borne diseases identified between 1999 and 2004, *Salmonella spp*. was the most prevalent in Brazil, with the predominance of *Salmonella Enteritidis* between 2001 and august 2005. According to the WHO, Salmonellais one of the pathogens that causes the greatest impact on population health, and is associated with outbreaks and with sporadic cases of food borne disease. According to data of the Brazilian Ministry of Health, 6,602 food borne disease outbreaks were recorded between 1999 and 2008, and *Salmonella spp*. was associated with43% of the cases in which the etiological agent was identified. In the European Union, *Salmonella Enteritidis*, *Salmonella Typhimurium*, *Salmonella Infantis*, *Salmonella Hadar* and *Salmonella Virchow* are considered by the European Food Safety Authority the most important serovars in terms of public health. [73] In Japan, between 1999 and 2002, 32% of the cases of foodborne infection were due to Salmonella, with *Enteritidis, Typhimurium* and *Infantis* as the predominant serovars. In 2005, in the US, the serovars that were most frequently isolated from human sources were *Salmonella Typhimurium*, *Salmonella Enteritidis, Salmonella Newport, Salmonella Heidelberg* and *Salmonella Javiana*. [15]

Besides the importance of preventive measures against the risk of Salmonellainfection inhumans, control of salmonellosis has a positive economic impact in countries whereoutbreaks occur. Estimated costs of medical expenses, sick leaves and loss of productivityrelated to the high incidence of salmonellosis in the US range from US$1.3 to US$4.0 billion a year.[64]

A large number of Salmonellahave to be ingested to cause gastroenteritis. Generally, theinfective dose depends on the serotype, ranging from 2.0x10^2 to 1.0x10^6CFU/g or mL. [36]Variation in the symptoms is also related to the type of food and the speciesof Salmonella involved, once species that are adapted to men require lower infective doses tocause the same characteristics symptoms of the disease.[53]Salmonella excretion in human and/or animal feces may contaminate the water, soil, otheranimals and foodstuffs. Animals are infected by direct contact with feces, contaminatedwater and food. Although broiler carcassesmay be contaminated with *Salmonella Enteritidis*, eggs and egg by-products – mainlyhomemade mayonnaise – are the main products responsible for outbreaks of the disease in humans. [61]

Depending on the host species and age, and on the pathogenicity of the microorganism and its adaptation to the host, Salmonellamay cause severe disease, or go unnoticed andremain in the host for months or years. In this case, the host will be a reservoir of thebacteria for susceptible animals.The most common symptoms include diarrhea, abdominal pain, vomit and nausea, and mayoccur together with prostration, muscle pain, drowsiness and fever. Although symptomsgenerally disappear after 5 days, the microorganisms may be excreted in the feces for many weeks. Children, mainly those younger than 1 year of age, elderly andimmunocompromised patients are much more susceptible to the disease, and may presentmore severe infections, such as sepsis, which may lead to death. [53]Since 1980, human outbreaks caused by *Salmonella Enteritidis*, showed common sources in the US, Great Britain and other European countries.[13] Epidemiological surveys from the CDC identified the consumption of eggs or egg-basedfoods as responsible for most of the outbreaks involving specific phagotypes (PT) of *Salmonella Enteritidis*; *PT-4* in European countries, and *PT-8* and *PT-13a* in the US. The predominant serotypes involved in foodborne diseases changed,in the past decades, from *Salmonella Agona, Salmonella Hadar and Salmonella Typhimurium* to *Salmonella Enteritidis*, which is the predominant cause of salmonellosisin several countries. [63]

The typification of serovars is important to track the source of infection. For example, *Salmonella Agona* affected humans in the US, in European countries and in Brazil. The intensive breeding system adopted by the poultry industry favors the introduction,establishment, permanence and dissemination of these bacteria. Therefore, the stage when animals are raised is very important in the dissemination of*Salmonella spp*. among the birds, and consequently, in giving rise to contaminated foodproducts. Salmonellamay affect all segments of poultry production, such asbreeder facilities, incubators, commercial raising operations, feed factories, slaughterhouses, transportation systems and commercialization facilities. [12]

4. CONCLUSION AND RECOMMENDATIONS

It appears that Salmonella is a common or perhaps the leading cause foodborne bacterial diseases, due to its ubiquitous occurrence in the natural environment and the intensive animal husbandry practices. Itis one of the most prevalent foodborne pathogen, its main reservoir being considered the shell egg. As the concerns related to the increasing human salmonellosis cases grow, the need for an application of preventive methods either at the farm level or during the processing steps is crucial for a better control of the foodborne outbreaks due to the consumption of this specific food product.The use of different preventive methods has the effect of reducing the likelihood that eggs become contaminated with *Salmonella spp*., especially with *S. Enteritidis*. On the farm level, the different preharvest methods may reduce the risk of egg contamination by interfering in the infection process and reducing the likelihood of this foodborne pathogen penetration in the forming egg. Further on, postharvest methods may reduce the risk of humansalmonellosis, by respecting the refrigeration step and by differentprocedures, either chemical or physical. These latter reducethe existing bacterial counts, especially on the eggshell and ensurethe microbiological quality of the shell eggs marketed in differentparts of the world. However, these postharvest chemical or physicalprocedures are not worldwide accepted and implemented; asresearch is still needed on this topic, to ensure that the nutritionalquality and properties of shell eggs are maintained, no matter the processing methods applied.

Based on the above conclusion the following recommendations are forwarded:

Eggs are among the most nutritious foods on earth and can be part of ahealthy diet. However, they are perishable just like raw meat, poultry, andfish. Unbroken, clean, fresh shell eggs may contain *S. Enteritidis* bacteria that can cause food-borne illness. Tobe safe, eggs must be properly handled, refrigerated, and cooked.

For producers

- It is essential that all eggs for sale must be candled to remove cracked eggs. Cracked eggs must be disposed of or only sold to businesses to be pasteurized.
- Nests should be kept as clean as possible by removing faeces and broken eggs out of nests and cleaning nest pads.
- Collect eggs daily and more often in the event of increased floor eggs and/ or in the event of hot weather conditions. Dirty or cracked eggs must be separated from clean eggs as soon as possible to minimize contamination.

- Cool all eggs immediately after collection. Cool rooms should be set at 15 ºC and be capable of maintaining this temperature.
- Premises and equipment for handling and storage of eggs must be maintained in a sanitized state fit for the production of food for human consumption.

For consumers

- Avoid using cracked eggs as they are more likely to be contaminated and thus present a higher health risk.
- Eating raw or undercooked eggs should be avoided, especially by young children, the elderly and immunocompromised persons.
- Hands, cooking utensils, and food-preparation surfaces should be washed with hot water and soap after contact with raw eggs or foods containing raw eggs.
- Avoid contaminating the egg contents with the outside of the shell when cracking.

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