ECOLOGY OF *SALMONELLA* AND MICROBIAL CONTAMINATION IN POSTHARVEST TABLE SHELL EGG PRODUCTION

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Abstract

Egg production and processing continue to be sources of foodborne *Salmonella* spp. that can lead to foodborne illnesses. *S.* Enteritidis remains one of the primary serovars associated with laying hens that can end up in the table shell eggs. There are several potential routes of *Salmonella* contamination both during egg production in the layer house as well as egg processing and beyond. This review briefly discusses preharvest aspects of *Salmonella* infection in laying hens and subsequent contamination of eggs. Most of the focus in this review will be on postharvest ecological and environmental aspects of *Salmonella* and general microbial table shell egg contamination occurring during collection, processing and retail. Current interventions as well as potential opportunities for additional efforts to limit *Salmonella* and microbial contamination in shell eggs during processing will also be discussed.

1.0 Introduction

Foodborne disease linked to *Salmonella* spp. continues to be problematic in the United States public health sector with extensive economic consequences and continued need for regulatory action (Scallan et al., 2011; Ricke et al., 2013d). Although foodborne pathogen *Salmonella* spp. can originate from a variety of food sources, poultry meat and table eggs remain prominent sources (Suslow et al. 2003; Foley et al., 2008, 2011, 2013; Hanning, et al., 2009; Erickson, 2010; Foley et al., 2011, 2013; Carrasco et al., 2012; Finstad et al., 2012; Howard et al., 2012; Koo et al. 2012; Painter et al., 2013). Several *Salmonella* serovars have been identified in outbreaks of human disease with *Salmonella enterica* serovar Typhimurium along with *S.* Enteritidis, *S.* Newport and *S.* Heidelberg being the ones most likely to occur as the causative isolate (Finstad et al., 2012; Foley et al., 2013).

For table shell eggs and the associated food products formulated with egg components *S.* Enteritidis has been the serovar that is usually identified as the primary foodborne disease causing serovar (Patrick et al., 2004; Braden et al., 2006; Curtis, 2007; Finstad et al, 2012; Howard et al., 2012; Martelli & Davies, 2012). Historically, *S.* Enteritidis emerged as primarily an egg related serovar that remained persistent in egg production cycles and could be identified with major salmonellosis outbreaks associated with *Salmonella* (St. Louis et al., 1988; Cogan & Humphrey, 2003; Martelli & Davies, 2012; Ricke et al., 2013a). This may in part be due to the ability of *S.* Enteritidis to gravitate toward the physiological processes that are exclusive to the generation of eggs by laying hens (Guard-Petter, 2001; Ricke, 2003a; Curtis, 2007; Gantois et al., 2009; Howard et al., 2012; Martelli & Davies, 2012; Galiş et al. 2013).

Consequently considerable effort has been made to document and describe the role that preharvest egg production plays in generation of contaminated eggs and how this impacts commercial egg production. Postharvest control measures for reducing *S.* Enteritidis contaminated eggs have also been documented to some extent. However, as alternative egg production systems and local egg marketing expands commercially in the U.S. some of these issues will need to be examined with restrictions unique to those systems in mind. Likewise as more emphasis is placed on sustainability and recycling this will potentially influence food safety of eggs. Finally, as international commercial egg production expands and opens new local markets egg safety may need to also be an issue under these particular production systems and retail circumstances. Therefore, the current review will focus on particular aspects of egg processing, carton packaging and handling in retail both in current production practices as well as historical developments and future considerations as retail production practices and associated markets become more variable.

2.0 Historical and current trends in commercial egg production

Since 2011 the average table layer hen numbers in the United States has continued to expand from 281.6 million layers in 2011 to 296.4 million layers as of Dec. 1, 2013 based on United States Department of Agriculture (USDA) estimates (Ibarburu & Bell, 2013). These recent flock numbers are reflective of the tremendous changes in the U.S. egg industry that have occurred over the past century where increases in the size of flocks have followed technological changes in layer building efficiency with single buildings housing thousands of birds and farm complexes capable of managing hundreds of thousands of birds (Parkhurst & Mountney, 1988; Klippen, 1990; Dunn & Madison, 1992; Bell, 1993; Anderson, 2009). Implementation of technologies such as mechanical egg gathering systems for in-line collection of eggs contributed

to this expansion of numbers of birds per flock and house (Bell et al., 2001). Likewise, innovations in egg processing plants for candling, egg washing, and packaging made further expansion possible (Klippen, 1990; Kuney et al., 1995; Hutchison et al., 2003; Musgrove, 2011). Consequently, the layer farms and number of flocks decreased while the number of birds per farm and per flock increased (Bell et al., 2001). This higher egg supply capacity from fewer flocks and farms and development of much more efficient packing plants along with the market impact of uneven regional changes in U.S. human population growth predictably led to industry wide interregional relocation shifts (Dunn & Madison, 1992; Bell 1993; Ryan et al., 1996). Regional differences in the U.S. were detectable not only from a pricing and product selection standpoint but the type of packaging, variety of products and egg quality (Bell et al., 2001; Koelkebeck et al., 2001).

Similar trends have occurred internationally as countries become more developed, their corresponding agricultural industries begin to expand and adjust to advanced technologies. This led to shifts in international markets which were extensively discussed elsewhere by Windhorst, (2006, 2008a,b, 2009) as a series of market analyses reviews and will not be discussed in detail in the current review. The following is a brief overview of these key conclusions previously made by Windhorst. For roughly three and half decades, global poultry meat and egg production outpaced beef, veal and swine (Windhorst, 2006). During this time shifts occurred as egg production volume in developing countries surpassed production in developed countries and by 2005 over 60 % originated from the Asian continent and nearly half came from three countries, China, India, and Japan with China producing over 40% and exhibiting tremendous growth during this time (Windhorst, 2006, 2008a, 2009). Just from 1990 to 2007 alone, nearly a doubling in global egg production occurred (Windhorst, 2009). However, the vast majority of

these eggs have remained in domestic markets with relatively few of the total eggs produced being exported and imported (Windhorst, 2006). Part of this may be due to the existence in some of these developing countries of small family flocks that are raised for subsistence consumption and local sales (McLeod et al., 2009). The global egg trade that does occur is highly regional with over two thirds of the exports and imports occurring in Europe with other regional trade zones centered in the American and Asian continents (Windhorst, 2008a,b,2009).

Since the early to mid 2000's several factors have come into play to once again shift the U.S. and international egg industry not only in terms of how eggs were marketed but how they were produced on commercial farms. Specialty egg brands that included eggs originating from organic and welfare managed production systems, nutritionally modified eggs, fertile eggs and eggs produced from hens fed all vegetable diets emerged in retail markets as viable, albeit more expensive options for customers (Patterson et al., 2001; Jones et al., 2010). Early interest in generating eggs that were considered more compatible with cholesterol reduction diets in humans led to hens fed vegetarian diets and commercially produced eggs containing higher levels of omega 3- fatty acids (Michella & Slaugh, 2000). As public health demands grew further, developments in fortifying egg nutritional value by increasing polyunsaturated fatty acid content, vitamin A, D and E by specific dietary strategies and feeding regimes of laying hens became an ongoing focal point (Rossi et al., 2013). Since the egg composition is feed dependent, this trend of dietary manipulation to further alter eggs to fit human nutritional and health needs is anticipated to continue as more understanding is achieved on the physiology and metabolism of egg formation (Shapira, 2010).

Animal welfare and subsequent consumer concerns have also impacted both the U.S. as well as the international egg industry. These concerns led the European Union to ban

conventional cage housing in 1999 with the idea of replacing them with alternative housing systems by 2012 (De Reu et al., 2008; Mench et al., 2012). These alternative housing systems consisted of either furnished cages that included a nest box, a dust bath, and a perch, or fully non-cage based systems (De Reu et al., 2008). Non-cage systems contain nest boxes and floor litter areas and are referred to either as aviaries which consist of some sort of platforms and slatted floors at different heights or if at one height simply called floor housing and when allowing access to outdoors can be considered free range (De Reu et al., 2008). Holt et al. (2011) concluded that as these regulations are implemented and alternative housing operations expand in commercial egg production systems, the impact on egg microbiology and pathogen prevalence will need to be assessed. Historically, these types of systems were in place in the mid-1900's and some of this information could be potentially gleaned from studies conducted at that time. However, Anderson (2009) points out that this would be problematic as much of the management data available from these earlier flock systems would not be applicable because the breeds and other factors were different than they are in current operations.

Most of the more recent microbiology studies have been conducted in Europe (Jones et al., 2011) and Holt et al., (2011) noted that these results were conflicting, with some concluding that conventional cage operations yielded a greater opportunity for *S.* Enteritidis incidence while others suggesting that nonconventional gave higher incidences of *S.* Enteritidis. Numerous confounding factors probably play a role in these different outcomes including the impact of flock size, type and frequency of sampling, seasonality, layer breed, management differences, and stress response, just to name a few (Curtis, 2007; De Reu et al., 2008, 2009; Anderson et al., 2009; Dewulf et al., 2011; Holt et al., 2011; Jones et al., 2011). Clearly more work needs to be done to not only characterize microbial contamination levels in these operations on a wider

scale, but develop analyses that can identify and account for the multiple factors which may be different among egg layer operations. Once this is accomplished, management practices and intervention strategies can be designed to be precisely applied to particular types of operations for more effective control of *Salmonella* incidence. In addition more effort may need to be directed toward detailed epidemiology of *Salmonella* isolates in these systems to avoid potential differences in serovars that could also confound control strategies.

The other major factor that is emerging in egg production and processing systems that potentially will impact egg microbiology is assessment and implementation of improved sustainability. Sustainability of agriculture in general has become an issue as energy costs both for production of cereal grains used as feed stocks and maintaining livestock housing have gone up while public concerns over environmental impact of confined animal operations have increased as well. For global egg production, Windhorst (2007) raised this question as a function of whether grain-fed layer flocks would be economically compromised as the arable land for corn and oil seed crops become more diverted into bioethanol and biodiesel production in different countries including the U.S. Increased interest in egg production sustainability also derives from other venues. Certainly, as discussed previously, the development and spread of alternative layer housing raises the issue of balancing animal welfare versus economics as a function of sustainable costs. Likewise, the emerging consumer driven market for organically produced poultry and animal products with the associated restrictions in grain production and management options has raised the question as to the sustainability of such operations for future expansion into more traditional agriculture markets (Ricke et al. 2012b). Organically produced eggs are also on the rise (van der Sluis, 2007; Anderson, 2009) so it is anticipated that similar questions will be raised for these types of egg production systems as well.

Sustainability of confined animal operations and impact on environment are closely linked. For egg production systems Xin et al. (2011) reviewed and compared environmental impacts between conventional caged housing systems and nonconventional systems and concluded that noncage houses generally have poorer air quality due to ammonia and dust and are generally less energy, feed and land efficient. They suggested that research was needed to compare the overall carbon footprint among the different housing systems to design means to reduce the environmental impact using life cycle assessment tools. Life cycle assessment (LCA) have been utilized to quantitate sustainability in a number of agriculture systems. Essentially LCA analyses involves constructing a balance sheet for all environmental inputs and outputs involved in the production, transportation, distribution, disposal and any other steps associated with the entire life cycle of a product (Guinée et al., 2011). Recently, several LCA studies have been made on egg production systems. Pelletier et al. (2014) used LCA to demonstrate that the overall environmental footprint for the U.S. egg industry was reduced in 2010 compared to 1960 and that the three primary environmental impacts during this time span were feed efficiency, feed composition, and manure management. Leinonen et al. (2012) using LCA to quantify environmental impact per kg eggs produced from cage, barn, free range, and organic United Kingdom (U.K.) production systems, concluded that organic eggs required the most hens and cage systems the least number of hens, with organic hens consuming the most feed. They also noted that feed production, processing and transportation elicited the largest impacts on the environmental footprint. Suggestions for further reducing the greenhouse gas environmental footprint in free range chickens have included substituting protein sources for the cereal grains currently used in these diets (Taylor et al., 2014).

In summary, several drivers are in play that could potentially be changing the dynamics of commercial egg operations on an international scale. As more efforts are made to change housing systems to address animal welfare concerns, and local free range and organic production system markets continue to increase, much of what is known about the prevalence of microorganisms in general and in particular *Salmonella* spp. may no longer apply in these modified systems. Likewise, further attempts to reduce the environmental footprint by altering feed composition and the handling of manure and other waste material could also alter the transmission patterns of the organisms. This may in turn have large impacts on egg food safety as international markets and regional production systems continue to shift. Consequently, it will be critical to examine what is already known about the ecology of *Salmonella* in egg production and processing and use this as starting point to revisit and in some cases identify potential critical control points that may be unique to these systems. The following sections will discuss *Salmonella* ecology in egg production and processing and examine current intervention strategies.

3.0 Egg production management on the farm and incidence of *Salmonella*

There are numerous opportunities for laying hens or for that matter chickens in commercial production systems in general to come in contact with *Salmonella* serovars. Traditionally, feed and feed ingredients were thought to be an important contributor to being a *Salmonella* spp. contact source for chickens during growth and under certain circumstances such as breeder flocks this could have a considerable impact due to the vertical integration nature of poultry production (Davies & Hinton, 2000; Jones & Richardson, 2004; Maciorowski et al., 2004, 2006b, 2007; Ricke, 2005; Jarquin et al., 2009; Davies & Wales, 2010; Ge et al., 2013). Therefore, it is not surprising that considerable effort has been made to not only implement

control measures in feeds and feed ingredients (Leeson & Marcotte, 1993; Ricke, 2003b, 2005; Maciorowski et al., 2004, 2007; Wales et al., 2010: Jones, 2011), but to develop sensitive detection methods for low levels of *Salmonella* potentially present in the feed matrix (Ricke et al., 1998; Maciorowski et al., 2000, 2005, 2006a; Jarquin et al., 2009; Park et al., 2011, 2014; Soria et al., 2011; Ricke et al., 2013c). Couple this with the fact that exposure to *S.* Enteritidis can originate as a function of laying hens coming in contact with a wide range of carriers well known for carrying *S.* Enteritidis such as insects, mice, rats, and other lesser known carriers in the houses where these hens reside and it becomes clear that there are numerous and somewhat unpredictable routes of exposure (Henzler, & Opitz, 1992; Hinkle & Hickle, 1999; Olsen & Hammack, 2000; Davies & Breslin, 2001; De Reu et al., 2008; Lapuz et al., 2008; Park et al., 2008; Holt et al., 2011; Galiş et al. 2013; Ricke et al., 2013a).

Before discussion on egg processing can begin, it is important to understand the relationship between the serovar *S.* Enteritidis and why it particularly occurs as a contaminant during all aspects of egg production. Historically, it became clear fairly early on that *S.* Enteritidis possessed unique aspects that led to its being particularly problematic during egg formation in laying hens (Guard-Petter, 2001; Holt, 1999, 2003, Ricke 2003a). One of the more revealing pieces of evidence for this was the discovery that certain laying hen management practices during egg production could enhance the likelihood of infection by *S.* Enteritidis. To achieve additional egg laying cycles for commercial and economical reasons, laying hen egg production can be halted, commonly referred to as molting, to literally shut down the reproductive tract and in turn arrest egg production for a period of time prior to initiating a second egg laying cycle (North & Bell, 1990; Bell, 2003; Berry, 2003; Park et al., 2004c; Ricke et al., 2010, 2013a). The induction of a molt period can be done via altering the diet and is

physiologically manifested in a laying hen in a variety a ways including hormonally, metabolically and immunologically among other detectable host responses (Berry, 2003; Kuenzel, 2003; Park et al., 2004c; Dunkley et al., 2007a,b; Kim et al., 2012; Ricke et al., 2010, 2013a).

Probably the most effective means for inducing a molt in actively egg producing laying hens was to simply to remove their feed for a period of time, then after sufficient time had lapsed re-introduce these hens to feed once again (Bell, 2003; Berry, 2003; Yousaf & Chaudhry, 2008). However, this led to the discovery that feed removal and subsequent emptying of the hen's gastrointestinal tract created a localized microenvironment that was conducive to *S.* Enteritidis colonization and systemic invasion (Durant et al., 1999; Holt, 1999, 2003; Ricke, 2003a; Dunkley et al., 2009). This microenvironment change could be linked to enhanced expression of pathogenesis genes in *S.* Enteritidis that corresponded to increased invasion and diminished gastrointestinal microflora activity and in some cases microbial population levels as well (Durant et al., 1999; Ricke 2003a; Dunkley et al., 2007c,d; 2009). While this was being established a flurry of alternative dietary options were proposed and examined that avoided feed removal and instead represented some sort of nutritional modification that would simultaneously ensure a molt response in the hen while retaining relatively normal gastrointestinal tract microenvironment and simulataneously serving as a barrier to *S.* Enteritidis (Corrier et al., 1997; Seo et al., 2001; Berry, 2003; Holt, 2003; Ricke 2003a: Moore et al., 2004; Park et al., 2004a,b,c; Woodward et al., 2005; McReynolds et al., 2006; Dunkley et al., 2007c,d; Donalson et al., 2008; Ricke et al., 2010, 2013a).

Other means to limit *S.* Enteritidis establishment in laying hens have also been explored. Administration of probiotic cultures that would lead to early establishment of a beneficial

gastrointestinal microflora that would in turn limit S. Enteritidis colonization have been explored usually in young broiler chicks for S. Typhimurium control but some have been shown to be effective against *S.* Enteritidis as well (Corrier et al., 1994a,b,1995; Nisbet et al., 1993, 1994, 1996a,b Ricke & Pillai, 1999; Nisbet, 2002; La Ragione & Woodward, 2003; Patterson & Burkholder, 2003; Revolledo et al., 2006; Higgins et al., 2007, 2008; Vilà et al., 2009; Hume, 2011; Siragusa & Ricke, 2012). Bacteriophages which can specifically lyse *S.* Enteritidis bacteriophage have also been examined as a means to remove already established populations of this pathogen either in table or fertile eggs or in the gastrointestinal tract (Borie et al., 2008; Robeson et al., 2011; Bardina et al., 2012; Ricke et al., 2012a; Henriques et al., 2013; Spricigo et al., 2013). Finally, there has been more interest generated on the development of live attenuated vaccines that are based on genetic modifications of *S.* Enteritidis to render it less virulent but still capable of inducing a hen to elicit a protective immune response against future exposure to *S.* Enteritidis (Babu et al., 2003; Dewaele et al., 2012; Revolledo & Ferreira, 2012).

In short, several extensive efforts have been made to short circuit establishment of *S.* Enteritidis in laying hen production systems and many of these approaches have demonstrated some success in decreasing the incidence of *S.* Enteritidis prior to egg collection and processing. However, numerous opportunities for contamination by *S.* Enteritidis and other *Salmonella* serovars can still occur during egg collection, processing, packaging, and in the final steps leading to retail and home use. The remainder of this review will focus on the potential for *Salmonella* contamination in the postharvest phases of egg production and processing.

4.0 Egg processing and microbial contamination – General Aspects

Table shell eggs continue to be a primary food source for human consumption either directly as an intact shell cooked product, contents removed from egg shell components,

prepared in some fashion and cooked, or as an ingredient in a wide range of prepared foods and baked goods. In 2009 alone, Americans consumed 250 eggs per person with total table eggs being produced standing at 78.5 billion with 24 billion broken for use in egg products (Ricke et al., 2013b). As discussed previously the U.S. egg industry has evolved tremendously in the past century. As egg processing equipment became more technologically developed the number of employees required to handle and inspect eggs decreased dramatically and the number of eggs that could be processed and shipped for retail increased with the development of equipment capable of washing, candling, sizing, and packaging over 180,000 eggs per hour (Musgrove, 2011). Eggs produced at the farm can enter the egg processing system either in an "in-line" production system where eggs are directly moved via conveyor belts from the layer farm where they are produced directly to an egg processing facility or as an "off-line" production system where eggs are collected at the farm and subsequently transported to another site for processing (Musgrove, 2011).

The multiple steps involved in egg processing represent numerous opportunities for microbiological contamination of the egg as it progresses through the system from the hen to the retail market. Identification of critical control points and conducting risk assessment studies have been attempted over the years to assign and prioritize where the optimal strategies for limiting exposure to *Salmonella* can be achieved during egg processing. Intuitively, some aspects such as the presence of cracks in egg shells represent a risk for bacterial penetration and contamination (Todd, 1996). Consequently, efforts to minimize crack formation and egg shell damage during processing, packaging and transportation would be considered desirable. Alteration of the egg shell surface integrity can easily occur to make it more vulnerable. For example, certain egg sanitizers can actually cause physical damage to the egg shell surface leading to the increased

penetration of egg shell by surface microbial contaminants (Kim & Slavik, 1996; Wang & Slavik, 1998).

Egg temperature has also been identified as a critical factor. Hutchinson et al (2004) concluded that egg wash and rinse water temperature below 34 °C led to detectable egg content contamination by *Salmonella*. However, this does not minimize risk from eggs that have become internally contaminated by transovarian infection of *S.* Enteritidis while the egg is being formed in the reproductive tract of the hen (Humphrey, 1994, 1999; Guard-Petter, 2001; Gantois et al., 2009). Clearly with these contaminated eggs, strategies that minimize growth of *S.* Enteritidis to keep populations low and developing methods to destroy this pathogen in the intact egg would need to be considered. Combining rapid cooling and whole shell egg pasteurization have been identified as effective means of reducing such risks (Whiting & Buchanan, 1997; Schroeder et al.,2006). When summarizing more recent risk assessment studies, Chemaly & Salvat, (2011) reported that rapid cooling would be helpful to reduce risk but that maintaining a continuous cold chain to limit condensation was critical and under some circumstances rapid chilling could lead to the formation of cracks in the egg shell. However, studies to evaluate all of the factors that influence internal temperatures in eggs are limited and information on all of these factors somewhat difficult to obtain.

A comprehensive study across several U.S. states was conducted to follow and compare egg surface and internal temperature from oviposition to distribution to delineate some of these factors for addressing risk questions raised by U.S. regulatory agencies regarding egg temperature and time relationships over the course of egg production, processing and retail distribution (Anderson et al., 2008; Koelkebeck et al., 2008; Patterson et al., 2008). Patterson et al. (2008) compared external and internal egg temperatures during production at the layer house and

concluded that the two separate measurements correlated very highly with each other and were influenced by state and seasonal differences. A similar seasonal and geographical impact was noted for egg processing operations and as expected by the authors, temperatures were higher for in-line operations compared to off-line operations since eggs from in-line systems come immediately from the production house to be processed and would be inherently warmer (Koelkebeck et al., 2008). Anderson et al (2008) when following temperature fluctuations of refrigerated delivery trucks also noteda seasonal by delivery interaction impact on egg temperature during transport for resale or distribution to retailers with less cooling occurring during short delivery times.

In summary, some obvious control points such as occurrence of cracked eggs and fluctuations in egg temperature have been identified as potential contributors to microbiological problems associated with eggs during the production and processing cycle. However, despite the efforts to provide more detailed information on certain aspects of egg production and processing, many issues remain and *Salmonella* outbreaks originating from table shell eggs continue. As discussed previously factors that contribute to layer hen infection and the corresponding vertical and horizontal spread of *Salmonella* have been well documented by numerous authors (Guard-Petter et al., 2001; Holt, 2003; 1999; Ricke, 2003a; Gantois et al., 2009; Ricke et al., 2013a). Along these lines, interventions that are either currently implemented or proposed have been well documented by many of these same authors. Consequently, these will not be discussed in this review. Instead the focus in this review will be on *Salmonella* incidence along with general microbial ecology and potential intervention measures during egg collection, processing, and distribution. These aspects of the egg industry have not necessarily been ignored historically but need to be revisited as the industry shifts more into alternative production systems and as the

international trade in eggs accelerates. Likewise, as consumers create market demands for small scale locally produced eggs in developed countries and developing countries start to collect, transport and distribute eggs from their small growers to more distant markets the opportunities for contact with *Salmonella* needs to be reconsidered under the environmental conditions imposed by these processing and retail systems. These issues will be addressed in the following sections.

5.0 Microbial contamination during egg collection at the farm to in-lineprocessing

The level of contact of eggs during the egg laying cycle with carriers and vectors of *Salmonella* represent potential sources of contamination and have been well documented (Baron & Jan, 2011). This would be of particular concern with chickens that have outdoors access such as what occurs in some organic operations and certainly with free range chickens. Consequently, limiting exposure to insects, mice, and other mobile carriers is warranted. Likewise, the environmental exposure to layer hen fecal material during egg laying could be problematic. Henzler et al. (1998) identified flocks with the highest level of *S.* Enteritidis contaminated manure as being the greatest public health risk along with age of flock where birds that were farther into the production cycle were of greater risk. This is supported by Hannah et al. (2011) when they compared aerobic bacterial populations from washed and unwashed shell eggs from caged and cage-free laying hens. Hannah et al. (2011) concluded that microbial levels were generally lower in eggs collected from laying hens housed in cages with manure removal belts.

Henzler et al. (1998) also noted that eggs from contaminated egg handling equipment were more likely to represent a greater risk. Contaminated egg equipment could be a key source of cross contamination. Murase et al., (2001) used pulse-field gel electrophoresis patterns to identify *Salmonella* serovars isolated from environmental samples of individual poultry houses

that were attached to an egg processing facility. They concluded that not only were the isolates the same between the poultry houses and the egg processing facility but that the egg belts were most likely to be a contributor to the dissemination of *Salmonella* serovars among houses. They also noted that the same isolate could be continually recovered from a house for over a year. This long term persistence has consequences not only as an ongoing source of contamination, but indicates that cleaning and disinfection protocols may be somewhat ineffective and need to be altered.

The type and composition of the egg belts may also be a factor. In an attempt to identify environmental areas in Canadian egg production that could be difficult for cleaning and sanitation programs Stocki et al. (2007) focused on egg conveyor belts. They pointed out that egg conveyor belts used in battery cage operations could be a potential attachment surface for persistence of *Salmonella* that also may be somewhat inaccessible to cleaning. In their study when they compared egg conveyor belts composed of either belt material made of vinyl, nylon, hemp, or plastic they observed that the vinyl conveyor belt material which had the least surface area for *Salmonella* colonization also resulted in the lowest recovery of *S.* Typhimurium and *S.* Enteritidis after washing and disinfection while hemp-plastic belt material had the greatest surface area and the corresponding highest level of remaining *S.* Typhimurium and *S.* Enteritidis. They concluded that conveyor belts made of woven materials were more susceptible to persistent and recalcitrant *Salmonella* colonization, and conversely belt materials with less surface area such as vinyl were better for effective *Salmonella* removal.

6.0 Microbial contamination during transportation to off-line egg processing facilities

Some of the general issues discussed with egg collection and microbial contamination would be similar for off-line processing but other unique factors have been identified for these

operations as well. Knape et (2002) compared microbial contamination levels in specific time intervals between on-line and off-line processing systems at four sites, namely the egg collection conveyor belt, during detergent application prior to exposure to the sanitizer, immediately after administering the sanitizer, and immediately before packaging. Using aerobic microbial plate counts as their microbial contamination monitor they noted that for the most part microbial populations were greater as the processing shift advanced over time in the off-line egg processing operations compared to the in-line operations. In particular by the time eggs were ready for packaging off-line aerobic bacterial contamination was greater at all time points versus in-line microbial contamination. They concluded that this may in part be due to the eggs arriving at the processing site were fresher for on-line production systems thus allowing less time for attachment and growth of microbial contaminants as well as less time for the organic material to adhere that might further facilitate microbial contamination and interfere with cleaning of the eggs.

Knape et al. (2002) also speculated that storage time may contribute to the higher levels of microbial contamination in off-line egg processing operations by enhancing adherence of organic matter on the shell as well as allowing for bacterial penetration of the egg shell. Musgrove and coworkers examined this in more detail by focusing on the nest run carts that consist of plastic flats placed on metal carts with unpainted wooden shelves used to transport eggs from the layer houses to the off-line egg processing facilities. As pointed out by Musgrove et al (2012) such carts may become problematic as eggs can become cracked, subsequently leaking onto the wooden shelves which in turn are used indefinitely and typically are not part of the sanitation regime. This was based on earlier work where Musgrove et al. (2004) surveyed 14 non-egg-contact surface multi-state commercial egg in-line, off-line and mixed (both in-line and

off-line) processors for general aerobic and *Enterobacteriacae* bacterial populations at the end of the processing day and before the next processing shift to assess sanitation impact. Of the various sites sampled, nest cart shelves and nest cart wheels yielded some of the highest microbial population counts with statistically non-significant differences between processing times.

In a followup study, Musgrove et al (2009) identified the isolates of *Enterobacteriacae* from nest cart shelves to belong to the genera *Citrobacter* spp., *Escherichia* spp., *Enterobacter* spp., *Klebsiella* spp., *Hafnia* spp., *Kluyvera* spp., *Leclercia* spp., and *Salmonella* spp., respectively and concluded that the shelves could serve as a reservoir for Enterobacteriacae including foodborne pathogens such as *Salmonella*. They confirmed this when they sampled shelves from nest carts used in off-line and mixed line operations and preenriched for *Salmonella* isolation and further identification (Musgrove et al., 2012). Shelves from off-line operations were 3-fold (36% total positives) more contaminated with *Salmonella* spp. with serotypes *S.* Cerro, *S.* Heidelberg, *S.* Infantis, *S.* Mbandanka, and *S.* Oranienberg recovered from the off-line operation and serotypes *S.* Anatum, *S.* Mbandanka, and *S.* Typhimurium recovered from the mixed operation facility.

8.0 Microbial contamination during egg processing

Once eggs are received in the egg processing plant either from on-line or off-line operations, additional opportunities for microbial cross contamination can occur during egg processing and subsequent packaging for retail shipment. Typically eggs arrive on conveyor belts from the corresponding on-line and off-line production sources go through an accumulator, followed by an egg washer, subsequently dried, oiled, candled and electronically checked for cracks, weighed, sorted, and finally packed for retail distribution (Musgrove, 2011). Much of the

egg handling during processing utilizes vacuum loaders, electronic surveillance and weighing systems enabling many more eggs to be processed and prepared for retail (Musgrove, 2011). However, despite the trend in increased automation, several research studies indicate that microbial and *Salmonella* cross contamination during egg processing still remain part of the ongoing concern as *Salmonella* outbreaks continue to occur (Davies & Breslin, 2003).

Early work by Jones et al. (1995) assessed *Salmonella* frequency from environmental samples, and external and internal egg contents collected at egg layer farms and an on-line processing facility in the U.S. and concluded that at although approximately 1 % of the commercial eggs were positive for *Salmonella* serovars externally, internal contamination was relatively infrequent. In a comprehensive U.K. field-based farm-egg packing plant study, Davies & Breslin (2003) sampled the packing plant floor, grading table, candlers, conveyor belts, rollers and handler tables either during operation or prior to the respective plant's disinfection schedule. They observed that all sites sampled were overall 20 to 30% contaminated with *Salmonella* and that these levels reflected the level of contamination with the corresponding layer house with eggs undergoing longer distances on roller conveyors prior to reaching the packing plant being less contaminated. To examine potential for cross contamination of eggs during processing in these packing plants, they sterilized eggs by boiling for 10 minutes and subsequently sent them through the packing plant 1 to 3 times, followed by culturing them for *Salmonella*. Although they did not detect *Salmonella* from sterile eggs passed through the plant once, by the third time they observed a minimum acquisition contamination rate of 0.3%. They concluded that disinfection only reduced these levels somewhat, which they believed was a reflection of their observation of generally poor cleaning in the egg packing plants resulting in detectable residual contamination.

Jones et al (2003) assessed the effectiveness of sanitation programs in southeastern U.S. egg processing plants by comparing on-line, off-line and mixed line shell egg processing plants located in different states either at the end of the operating day or the next morning prior to the start of operations. They used sterile gauze pads to sample sixteen direct and indirect contact sites within these plants including belts, scales, check detector, vacuum loaders, egg washer tank brushes, washer lids and tank walls, oiler flaps, and packer head belts, among others for determining the levels of aerobic bacteria and *Enterobacteriacae*. In general, they could not detect aerobic bacterial population differences between end of the operating day versus the next morning which has also been reported in other studies (Musgrove et al., 2004). However, they did observe high levels of bacteria recovered from the washer tank wall, the rewash belt and the vacuum loaders with bacterial counts becoming lower as the eggs moved further along into cleaner areas of the processing line. They concluded that there is the potential need for development and application of cleaning chemicals that better take into account the challenges of a commercial operation and that sanitation could potentially be made more effective if separated into cleaning zones based on the particular types of equipment involved in the different components of the egg packing plant operation.

Musgrove et al. (2005) conducted an intensive microbial examination of the individual stages of egg processing in mixed line operations by using egg shell rinses of eggs collected at different processing sites and enumerating total aerobic bacteria, yeast and molds, *E. coli*, and *Enterobacteriacae* along with preenrichment for *Salmonella* isolation. They noted that generally microbial populations from shell rinses were highest at the accumulator and the rewash belt. They also concluded that prevalence for individual groups of bacteria for the most part also generally declined as eggs transitioned from preprocessing to post-processing while overall

Salmonella prevalence ranged at approximately 10% with considerable differences between individual processing plants. They also observed that *Salmonella* was isolated at every site in all stages of egg processing at least once when combining all isolations across all visits and plants. In a followup study, Musgrove et al. (2008) used commercial biochemical-based identification assays and identified *Escherichia coli* and *Enterobacter* spp. from most of the plants with lesser frequencies of other *Enterobacteriacae* genera including *Citrobacter* and *Klebsiella* and non-*Enterobacteriacae* bacteria including *Pseudomonas*, *Aeromonas* and *Vibrio* among others.

When Jones & Musgrove (2008a,b) examined sterile saline rinsates from vacuum loaders which are used to transfer eggs from incoming egg flats in mixed and off-site egg production facilities, they observed higher aerobic bacterial populations in mixed operations but higher *Enterobacteriacae* in the off-line facility. Based on biochemical test, predominant bacteria included *Enterobacter, Klebsiella, Escherichia, Citrobacter,* and *Serratia. Campylobacter* and *Salmonella* were recovered at rates of 1.6 and 3.3 %, respectively, while *Listeria* were recovered in 72 % of the samples (of which 98.8% were *L. innocua* and 1.2% were *L. monocytogenes*). The authors speculated that vacuum loader cups could serve as a reservoir for *Listeria*. They also concluded that bacterial growth niches may be appearing in these loader cups thus stressing the need for better cleaning and sanitation approaches for these particular devices. It is not clear where the *Listeria* may be originating from as they seem to be linked with facilities that have off-line capabilities. Whether they originally were attached to incoming egg flat surfaces or were part of the plant facility environment microflora remains to be determined. Certainly, *Listeria* spp. are well known inhabitants of a wide range of food processing plant environments (Milillo et al. 2012a) but several species have been isolated from poultry origins as well including pasture flock poultry birds, eggs and egg wash water (Laird et al, 1991; Farber et al., 1992; Jones et al,

2006; Milillo et al., 2012b). More surveillance research needs to be done to determine the extent of *Listeria* contamination in egg processing plants and the potential risk to public health.

9.0 Egg wash water and sanitation

Several countries such as the United States, Japan, and Canada wash and grade eggs prior to shipping them out for retail distribution, but egg washing is generally not allowed or practiced in the European Union (Hutchinson, 2003; Musgrove, 2011; Howard et al., 2012). As described by Hutchinson (2003) the egg washing process essentially involves four steps, namely wetting, washing, rinsing and drying. Egg washing procedures conducted in commercial operations typically employ a mechanical washing apparatus that mists an alkaline detergent solution across eggs as they are brushed from side to side while moving along the egg conveyor belt followed by a final rinse usually containing some sort of chlorine or quaternary based sanitizer (Hutchinson et al., 2003; Northcutt et al., 2005; Howard et al., 2012). Once the eggs have been washed the remaining egg wash and rinse waters are combined, filtered and recirculated to a wash tank where they can be reheated for repeat usage in the initial wetting and cleaning stages of the egg washer cycle (Hutchinson, 2003; Northcutt et al., 2005; Howard et al. 2012). Details on the development, management and application of egg wash water has been extensively reviewed elsewhere and will only be briefly discussed in the current review (Moats, 1981; Hutchinson et al., 2003; Messens, 2011).

While reusing egg wash water to minimize overall water use is desirable there are several potential issues with this reuse of egg wash water (Hutchinson, 2003). Even though the alkaline pH of the egg wash water is designed to not only clean egg shells but limit bacterial proliferation accumulation of organic matter from recirculation can dilute its efficacy (Kinner and Moats, 1981; Howard et al., 2012). To address this, Northcutt et al. (2005) profiled the potential

fluctuations in the composition of commercial shell egg wash water from three in-line egg processors in southeastern U.S.by monitoring temperature, pH, chlorine, soluble iron (ferrous), total dissolved solids, total suspended solids, total Kjeldahl nitrogen, and chemical oxygen demand. They compared fresh incoming tap water with water sampled after the first 2 hours of operation from two egg shell washers that used an end-to-end arrangement as a dual washer system in these facilities. In general they observed considerable variation among plants for most of these parameters and concluded that differences occurred in age of plant and equipment, management of the plant, source of eggs, number of broken eggs among other factors. In particular when decreases in pH and increases in soluble iron occur, these could be especially problematic as both can lead to increases in bacterial growth and contamination including *Salmonella* spp. if they reach certain levels where they no longer limit bacterial growth and proliferation (Hutchinson et al., 2003; Messens, 2011; Howard et al., 2012).

The fluctuations in chemical composition raise the general issue as to whether egg washing effectively limits microbial contamination. To determine this, Jones et al. (2004) profiled microbial populations by collecting eggs before and after egg processing over three consecutive days from a commercial in-line processor with a dual tank egg washer. They stored eggs over ten weeks of storage and enumerated total aerobic bacteria, pseudomonads, yeast, molds and *Enterobacteriacae* from both external egg shell surface rinses and internal egg contents. While they did not observe differences in total aerobic bacteria, yeasts and molds between unwashed and washed egg contents, they did report substantially less external total aerobic bacterial, and yeast and mold populations in washed eggs compared to unwashed eggs while only low levels of *Enterobacteriacae* and pseudomonads were detected in any of the eggs sampled. It would be of interest to develop more detailed microbial profiles of egg shell

601 microbial populations to determine shifts in specific groups and even individual microorganisms
602 during egg processing. Likewise, the interaction between microflora on incoming eggs versus
603 resident egg processing plant microbial populations would be helpful to elucidate their respective
604 impacts on the efficacy of egg washes and sanitizers. As microbial identification technology
605 progresses with next generation sequence capabilities becoming more routine and readily
606 available, extensive characterization of these corresponding egg processing plant and egg shell
607 surface microbiomes may become a reality.

608 Despite the apparent effectiveness of egg washing, as Jones et al. (2004) pointed out from
609 their earlier studies (Jones et al., 2003), reduced bacterial contamination is not always observed
610 in commercial egg processing operations. This occurs despite the employment of some sort of
611 chemical sanitizer during the egg processing cycle. Sanitizers used in egg processor facilities are
612 generally applied immediately after the alkaline egg wash cleaning step as a rinse solution
613 containing a chlorine concentration of 100 to 200 ppm, or a quaternary ammonium-based
614 compound (Hutchinson et al.,, 2003; Howard et al., 2012). Given the inconsistencies in effective
615 microbial contamination control and issues such as reducing cost, a wide range of sanitizers and
616 other decontamination technologies for potential use in egg processing have been examined over
617 the past several years (Howard et al., 2012). Individual compounds and other strategies have
618 been described extensively elsewhere (Berardinelli et al., 2011; Howard et al., 2012; Galiş et al.
619 2013) and will only be briefly discussed here. Generally, the sanitizer approaches can be
620 classified as application of either unique chemical or biological compounds administered in a
621 similar manner as the more traditional sanitizer compounds. These would include agents such as
622 botanical compounds, enzyme catalyzed bactericidal reactions, or electrolyzed water (Kuo et al.,
623 1997b; McKee et al., 1998; Knape et al., 1999, 2001; Russell, 2003; Bialka et al., 2004; Park et

al., 2005; Cao et al., 2009; Upadhyaya et al., 2013). Nonchemical approaches to decontamination include subjecting shell eggs or egg processing equipment to some sort of light, gas or other form of radiation that is bactericidal such as ultraviolet light, non-thermal atmospheric gas plasma, ozone, or ionizing radiation (Gao et al., 1997; Kuo et al., 1997a,c; ; Chavez et al., 2002; Rodriguez-Romo & Yousef, 2005; Keklik et al.,2010, Ragni et al., 2010). Although many of these approaches show promise much remains to be done to assess effectiveness under different processing conditions as well as the need to address cost and economics for scaling up some of these technologies.

10.0 Egg retail and microbial contamination

Once eggs are processed and sorted they are packaged for retail and distributed to retail markets. Starting in the 1970's considerable effort was made to compare different types of egg packaging that was best suited not only for retail market display but protected eggs from damage to the shell during transportation as they traveled to their respective market destinations. Most of the research and development focus was directed toward either expanded polystyrene (EPS) or molded paper pulp (MPP). Early work addressed issues such as ability of particular egg carton types to cushion eggs sufficiently to minimize crack formation (Mellor and Gardner, 1970, 1975; Mellor et al., 1975; Denton et al., 1981; Lederer, 1983; Nethercote et al. 1974; Seydim & Dawson, 1999). Nethercote et al. (1974) concluded that for both polystyrene and molded pulp cartons that design was more important than carton material. Much of the later work has been directed towards the response of these types of egg cartons to temperature fluctuations during storage and transport and rapid cooling systems (Thompson et al., 2000).

While egg packaging has evolved to a large extent in the U.S., potential contamination issues remain with certain segments of the egg retail market. Historically, used cases, fillers and

flats were considered readily available for reuse and this apparently occurred where deficits were present (Eggleton & Carpenter, 1961). However, Eggleton & Carpenter (1961) after surveying the egg industry at that time recommended that damaged and soiled flats needed to be avoided and controls should be exercised over reuse policies. Board et al. (1963) surveyed new, used, and dirty egg flats and observed that they could become heavily contaminated especially if they had egg albumen or yolk material remaining on them. Banwart, (1964) demonstrated that *Salmonella* and other egg contaminant bacteria could attach to these egg flats and that only autoclaving the flats completely eliminated them.

This issue has re-emerged for certain local markets where retail egg containers can be reused and there is the potential for contamination to occur over time if these are not properly sanitized. There is evidence for this potential risk based on studies conducted on retail egg markets in other countries. Suresh et al., (2006) collected samples of egg shells, egg contents, and egg trays in South India retail markets and isolated and identified *Salmonella* spp. from these sources. Based on the recovered levels of *Salmonella* from these various sources they concluded that reused egg trays were a potential risk for exposure to *Salmonella*. In a later study, Singh et al., (2010) profiled eggs transported from farms to wholesale and retail markets located in North India in an attempt to characterize and track where *Salmonella* cross contamination might be occurring. *S.* Typhimurium was the predominant serovar and they observed a higher incidence from eggs collected in the retail markets versus the levels they isolated in the fresh eggs from the egg layer farms. Based on these comparisons, they suggested that surface contamination must have occurred during handling, storage, and transportation of the eggs from the farms to the market. Utrarachkij et al., (2012) conducted an in-depth study on the level of *Salmonella* contamination in samples they had collected from eggshells, egg contents, reusable egg trays and

associated environments in Thailand egg farms and markets. After a comparison among these multiple sources they concluded that reusable egg trays used for these eggs could serve as a potential source of horizontal *Salmonella* transmission.

Based on these studies it is clear that little is known about the interaction between the type of retail packaging and the cross contamination that may occur between it and the table shell egg. Certainly opportunities exist for potential microbial cross contamination depending on the type of packaging material, particularly if it is reused and not properly cleaned. More comprehensive microbial studies need to be conducted on different types of packaging materials to better identify the dynamics of microbial diversity and their potential interactions with foodborne pathogens such as *Salmonella* spp. As discussed with egg processing, advanced molecular technologies such as complete microbiome sequencing offer opportunities to much more thoroughly characterize these microbial population and delineate patterns that may contribute to persistent contamination problems. This is critical as some of these complex microbial populations that can be present on some surfaces may possess capabilities of forming biofilms which could harbor pathogens thus rendering the pathogens somewhat protected from typical sanitation protocols and administration of sanitizing agents. The other development that may prove useful to egg packaging is the development of unique packaging materials that possess antimicrobial characteristics that could serve as a barrier for preventing cross contamination. There is precedent for this in the food industry with other food commodities (Suppakul et al. 2003). One could envision such packaging not only containing anitmicrobials but as technologies develop possessing sensor capabilities for monitoring environmental conditions such as temperatures along with precise tracking capabilities and perhaps eventually incorporating direct microbial contamination level indicators.

11.0 Conclusions and future directions

Salmonellosis continues to be major cause of foodborne disease in the U.S. with over one million cases occurring annually costing several billion dollars (Scallan et al., 2011; Foley, et al., 2013). Poultry products are still one of the major sources of Salmonella in the U.S. (Foley et al., 2011; 2013; Painter et al., 2013). *Salmonella* and microbial contamination continue to be issues for the commercial egg industry, but the sources and cross contamination routes have changed over time. In addition, different *Salmonella* serovars have become more closely identified with eggs, such as *S.* Enteritidis which appears to have some host affinity for infecting laying hens. This is partly due to the evolution of *Salmonella* serovars over the years and also to some extent the result of changes in egg production management. In addition, the impact of recent salmonellosis egg associated outbreaks have been more prominent from a public health standpoint, not only because of the larger egg operations involved but also because of the more comprehensive and advanced molecular-based trace back technologies that are now available and can be routinely implemented. These trends will remain as the commercial U.S. egg industry continues to evolve from a small flock local market in the last century to the large flock-multiple house and egg processing plant complex production systems common to the current industry. However, as the egg industry has developed into a vertically integrated system, more narrowly focused commercial niche markets have emerged such as speciality or designer eggs along with the ever increasing consumer demand for organic and free range layer flocks produced eggs. Some of these systems such as free range chickens present additional challenges for managing food safety. Likewise, as the egg industry shifts more internationally and trade between countries expands, food safety issues associated with these eggs may also become more prevalent.

However, much has been learned about the ecology of *Salmonella* in layer flocks and how this influences subsequent egg contamination. While most *Salmonella* penetrate eggs from the exterior shell, *S.* Enteritidis has shown the ability to infect hens and colonize the reproductive tract resulting in contamination of the internal contents of the egg. Several environmental factors influenced this, but certain management practices were identified as primary culprits for creating a gastrointestinal tract microenvironment that enhanced *S.* Enteritidis invasiveness. Since these factors became known, a number of management strategies have emerged to limit this. Likewise, as eggs are collected from the farm and either sent directly via conveyor belt to an on-line egg processing plant or transported to an off-line processing plant, more is now known about the microbial ecology of eggs as they enter the plant. Problem areas still occur, in particular during transport to off-line facilities and the use of nest carts. Other environmental areas for microbial contamination include certain types of conveyor belts and vacuum loaders. During egg processing the use of egg washes and sanitizers can help to reduce the bacterial load during egg processing but improvements and more sanitizer options are needed. In particular, it appears that *Salmonella* cross contamination of external egg surfaces can occur during processing. Finally, opportunities exist for potential contamination at the retail market depending on the type of packaging material. Clearly, resuse of egg trays as seen in certain parts of the world have been identified as a potential high risk source of *Salmonella* contamination. This is supported by work in U.S. during the early 1960's which demonstrated that trays soiled by egg contents that had been reused were easily contaminated by *Salmonella* attachment to these surfaces and the pathogen could only be eliminated by the extreme measure of autoclaving. This may be particularly important in local egg retail markets where egg containers may be reused without

proper cleaning. Clearly, efforts to better communicate risks to the public may be warranted as well.

There continues to be a need for improvement in food safety especially as it is associated with all aspects of egg production, processing and retail. This will require not only further development of control measures, but detailed identification of critical high risk areas where microbial contamination is most likely to occur. Consequently, an in-depth profile of the microbial populations involved at various stages of egg production, particularly during transport, arrival at the egg processing plant and during the various stages of egg washing, oiling, sorting and packaging is needed. Advanced molecular approaches such as microbiome analyses offer intriguing possibilities to provide more details on how environmental factors such as changes in egg wash water chemistry and temperature may influence the microflora on the egg shell surface. Likewise, functional genomic analysis offers the opportunity to understand how *Salmonella* spp. may respond to these same conditions. Identifying responses at the genomic level may lead to development of unique antimicrobials and sanitizer strategies that can more precisely target *Salmonella* spp. at all phases of egg production. The ultimate goal will be to produce a safer egg with a longer shelf life at the retail market.

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REFERENCES

Anderson, K.E. (2009). Overview of natural and organic egg production: Looking back to the future. *J. Appl. Poultry Res.* **18**, 348-354.

Anderson, K.E., P. H. Patterson, K. W. Koelkebeck, M.J. Darre, J.B. Carey, D.U. Ahn, R.A. Ernst, D.R. Kuney, & D.R. Jones. 2008. Temperature sequence of eggs from oviposition through distribution: Transportation—Part 3. Poultry Sci. 87: 1195–1201.

Babu, U., Scott, M., Myers, M.J., Okamura, M., Gaines, D., Yancy, H.F., Lillehoj, H., Heckert, R.A., & Raybourne, R.B. (2003). Effects of live attenuated and killed *Salmonella* vaccine on T-lymphocyte mediated immunity in laying hens. Veterinary Immunol. Immunopathol. **91**, 39-44.

Banwart, G. F. (1964). Elimination of *Salmonellae* from inoculated filler flats. *Poultry Sci.* **43**, 939-941.

Bardina, C., Spricigo, D.A., Cortés,P. & Llagostera, M. (2012). Significance of the bacteriophage treatment schedule in reducing *Salmonella* colonization of poultry. *Appl. Environ. Microbiol.* **78**, 6600–6607.

Baron, F. & Jan, S. (2011). Chapter 14. Egg and egg product microbiology. In: *Improving the safety and quality of eggs and egg products. Volume 2: Egg safety and nutritional quality*. F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.330-350. Woodhead Publishing Limited, Oxford, UK.

Bell, D. (1993). The egg industry of California and the USA in the 1990s: A survey of systems. *World's J. Poultry Sci.* **49**, 58-64.

Bell, D. D. (2003). Historical and current molting practices in the U. S. table egg industry. *Poultry Sci.* **82**, 965-970.

Bell, D.D., Patterson, P.H., Koelkebeck, K.W., Anderson, K.E., Darre, M.J., Carey, J.B., Kuney, D.R., & Zeidler, G. (2001). Egg Marketing in National Supermarkets: Egg Quality—Part 1. *Poultry Sci.* **80,** 383–389.

Berardinelli, A., Cevoli, C., Fabbri, A., Guerzoini, M.E., Manfreda, G., Pasquali, F., Ragni, L. & Vannini, L. (2011). Chapter 10. Alternative egg decontamination techniques to washing. In: *Improving the safety and quality of eggs and egg products. Volume 2: Egg safety and nutritional quality*. F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.330-350. Woodhead Publishing Limited, Oxford, UK.

Berry, W.D. (2003). The physiology of induced molting. *Poultry Sci.* **82**, 971-980.

Bialka, K.L., Demirci, A., Knabel, S.J., Patterson, P.H., & Puri, V.M. (2004). Efficacy of electrolyzed oxidizing water for the microbial safety and quality of eggs. *Poultry Sci.* **83**, 2071-2078.

Board, R.G., Ayres, J.C., Kraft, A.A., & Forsythe, R.H. (1963). The microbiological contamination of egg shells and egg packing materials. *Poultry Sci***. 42**, 584-595.

Borie, C., Albala, I., P. Sànchez, P., M. L. Sánchez, M.L., S. Ramírez, S., Navarro, C., Morales, M.A., Retamales, J., & Robeson, J. (2008). Bacteriophage treatment reduces Salmonella colonization of infected chickens. *Avian Dis.* **52**, 64–67.

Braden, C. R. (2006). *Salmonella esterica* serotype Enteritidis and eggs: a national epidemic in the United States. *Clinical Infectious Diseases, 43*: 512-517.

Cao, W., Zhu, Z.W., Shi, Z.X., Wang, C.Y. & Li, B.M. (2009) Efficiency of slightly acidic electrolyzed water for inactivation of *Salmonella enteritidis* and its contaminated shell eggs. *Int. J. Food Microbiol*. **130**, 88–93.

802 Carrasco, E., Morales-Rueda, A., & García-Gimeno, R.M.. (2012). Cross-contamination and
803 recontamination by *Salmonella* in foods: A review. Food Res. Int. **45**, 545–556.
804 Chavez, C., Knape, K.D., Coufal, C.D., & Carey, J.B. **(**2002) Reduction of eggshell aerobic plate
805 counts by ultraviolet irradiation. *Poultry Sci.* **81**, 1132–1135.
806 Chemaly, M. & Salvat, G. (2011) Chapter 2. Foodborne disease associated with
807 eggs: microbial hazards and *Salmonella* Enteritidis risk assessment.. In: *Improving the*
808 *safety and quality of eggs and egg products. Volume 2: Egg safety and nutritional*
809 *quality.* F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.34-45, Woodhead Publishing
810 Limited, Oxford, UK.
811 Cogan, T. A. & Humphrey, T. J. (2003). The rise and fall of *Salmonella* Enteritidis in the UK. *J.*
812 *Appl. Microbiol.* **94 (Suppl.)**, 114S–119S.
813 Corrier, D. E., Nisbet, D.J., Hargis, B.M., Holt, P.S., and DeLoach, J.R. (1997). Provision of
814 lactose to molting hens enhances resistance to *Salmonella enteritidis* colonization. *J.*
815 *Food Prot.* **60**, 10–15.
816 Corrier, D.E., Nisbet, D.J., Scanlan, C.M., Hollister, A.G., & DeLoach, J.R. (1995). Control of
817 *Salmonella typhimurium* colonization in broiler chicks with a continuous-flow
818 characterized mixed culture of cecal bacteria. *Poultry Sci.* **74,** 916–924.
819 Corrier, D.E., Nisbet, D.J., Hollister, A.G., Beier, R.C., Scanlan, C.M., Hargis, B.M., &
820 DeLoach. J.R. (1994a). Resistance against *Salmonella enteritidis* cecal colonization in
821 Leghorn chicks by vent lip application of cecal bacteria culture. *Poultry Sci.* **73**, 648–652.
822 Corrier, D. E., Nisbet, D.J., Scanlan, C.M., Tellez, G., Hargis, B.M., & DeLoach, J.R. (1994b).
823 Inhibition of *Salmonella enteritidis* cecal and organ colonization in Leghorn chicks by a
824 defined culture of cecal bacteria and dietary lactose. *J. Food Prot.* **57**, 377–381.
825 Curtis, P. (2007). Microbiological challenges of poultry egg production in the US. World's
826 Poultry Sci. J. **63**, 301-307.
827 Davies, R. H. & Wales, A. D. (2010). Investigations into *Salmonella* contamination in poultry
828 feedmills in the United Kingdom. *J. Appl. Microbiol.* **109**,1430–1440.
829 Davies, R. & Breslin, M. (2003). Investigation of Salmonella contamination and disinfection
830 in farm egg-packing plants. *J. Appl. Microbiol.* **94**, 191–196.
831 Davies, R. & Breslin, M. (2001). Environmental contamination and detection of *Salmonella*
832 *enterica* serovar *enteritidis* in laying flocks. *The Veterinary Rec.* **149**, 699-704.
833 Davies, R. H. & Hinton, M. H. (2000). *Salmonella* in animal feed. In: C. Wray and A. Wray
834 (Eds) *Salmonella in domestic animals*, pp. 285–300. Wallingford, UK: CABI Publishing.
835 Denton, J.H., Mellor, D.B., and Gardner, F.A. (1981). The effect of egg carton and case type on
836 egg shell damage. *Poultry Sci.* **60**, 145-150.
837 De Reu, K., Rodenburg, T.B., Grijspeerdt, K., Messens, W., Heyndrickx, M., Tuyttens, F.A.M.,
838 Sonck, B., Zoons, J., & Herman, L.. (2009). Bacteriological contamination, dirt, and
839 cracks of eggshells in furnished cages and noncage systems for laying hens: An
840 international on-farm comparison. *Poultry Sci.* **88**, 2442–2448.
841 De Reu, K., Messens, W., Heyndrickx, M., Rodenburg, T.B., Uyttendaele, M., & Herman, L.
842 (2008). Bacterial contamination of table eggs and the influence of housing systems.
843 *Worlds' Poultry Sci. J.* **64,** 5-19.
844 Dewaele, I., Rasschaert, G., Wildemauwe, C., Van Meirhaeghe, H., Vanrobaeys, M., De Graef,
845 E. Herman, L., Ducatelle, R., Heyndrickx, M., & De Reu, K. (2012). Polyphasic
846 characterization of *Salmonella* Enteritidis isolates on persistently contaminated layer

847 farms during the implementation of a national control program with obligatory
848 vaccination: A longitudinal study. *Poultry Sci.* **91**, 2727–2735.
849 Dewulf, J., Van Hoorebeke, S., & Van Immerseel, F. (2011). Chapter 6. Epidemiology of
850 *Salmonella* infections in laying hens with special emphasis on the influence of the
851 housing system. In: *Improving the safety and quality of eggs and egg products. Volume 2:*
852 *Egg safety and nutritional quality.* F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.107-
853 119. Woodhead Publishing Limited, Oxford, UK.
854 Donalson, L.M., McReynolds, J.L., Kim, W.K., Chalova, V.I., Woodward, C.L., Kubena, L.F.,
855 Nisbet, D.J., & Ricke, S.C. (2008). The influence of a fructooligosaccharide prebiotic
856 combined with alfalfa molt diets on the gastrointestinal tract fermentation, *Salmonella*
857 Enteritidis infection, and intestinal shedding in laying hens. *Poultry Sci.* **87**, 1253-1262.
858 Dunkley, C. S., McReynolds, J.L., Dunkley, K.D., Kubena, L.F., Nisbet, D.J., & Ricke, S.C.
859 (2007a). Molting in *Salmonella* Enteritidis-challenged laying hens fed alfalfa crumbles.
860 III. Blood plasma metabolite response. *Poultry Sci.* **86**, 2492-2501.
861 Dunkley, C.S., McReynolds, J.L., Dunkley, K.D., Njongmeta, L.N., Berghman, L.R., Kubena,
862 L.F., Nisbet, D.J., & Ricke, S.C. (2007b).Molting in *Salmonella* Enteritidis-challenged
863 laying hens fed alfalfa crumbles. IV. immune and stress protein response. *Poultry Sci.* **86**,
864 2502-2508.
865 Dunkley, K.D., Callaway, T.R., Chalova, V. I., McReynolds, J. L., Hume, M. E., Dunkley, C. S.,
866 Kubena, L. F., Nisbet, D. J., & Ricke, S. C. (2009). Foodborne *Salmonella* ecology in the
867 avian gastrointestinal tract. *Anaerobe*, **15 (Sp. Iss. SI)**, 26-35.
868 Dunkley, K.D., McReynolds, J.L., Hume, M.E., Dunkley, C.S., Callaway, T.R., Kubena, L.F.,
869 Nisbet, D.J., & Ricke, S.C. (2007c). Molting in *Salmonella* Enteritidis-challenged laying
870 hens fed alfalfa crumbles. I. *Salmonella* Enteritidis colonization and virulence gene *hilA*
871 response. *Poultry Sci.* **86**, 1633-1639.
872 Dunkley, K.D., McReynolds, J.L., Hume, M.E., Dunkley, C.S., Callaway, T.R., Kubena, L.F.,
873 Nisbet, D.J., & Ricke, S.C. (2007d).Molting in *Salmonella* Enteritidis-challenged laying
874 hens fed alfalfa crumbles. II. Fermentation and microbial ecology response. *Poultry Sci.*
875 **86**, 2101-2109.
876 Dunn, J.W. & Madison, M.E. (1992). Interregional competition for eggs. *Journal of Applied*
877 *Poultry Res.* **1**, 48-55.
878 Durant, J.A., Corrier, D.E., Byrd, J.A., Stanker, L.H., & Ricke, S.C. (1999). Feed deprivation
879 affects crop environment and modulates *Salmonella enteritidis* colonization and invasion
880 of leghorn hens. *Appl. Environ. Microbiol.* **65**, 1919-1923.
881 Eggleton, L.Z. & Carpenter, C.D. (1961). The use of reclaimed egg cases in the shell egg and
882 egg products trade. *Poultry Sci.* **40**, 720-727.
883 Erickson, M.C. (2010). Microbial risks associated with cabbage, carrots, celery, onions, and deli
884 salads made with these produce items. *Comp. Revs. Food Sci. Food Safety.* **9**, 602-619.
885 Farber, J.M., Daley, E., & Coates, F. (1992) Presence of *Listeria* spp. in whole eggs and wash
886 water samples from Ontario and Quebec. *Food Res. Int.* **25**, 143-145.
887 Finstad, S., O'Bryan, C.A., Marcy, J.A., Crandall, P.G., & Ricke, S.C. (2012). *Salmonella* and
888 broiler production in the United States: relationship to foodborne salmonellosis. *Food*
889 *Res. Int.* **45**, 789-794.
890 Foley, S.L.,Johnson, T.J., Ricke, S.C., Nayak, R. & Danzeisen, J. (2013). *Salmonella*
891 pathogenicity and host adaptation in chicken-associated serovars. *Microbiol. Mol. Biol.*
892 *Revs.* **77**, 582-607.

Foley, S., R. Nayak, R.,Hanning, I.B., Johnson, T.L., Han, J., & Ricke, S.C. (2011). Population dynamics of *Salmonella enterica* serotypes in commercial egg and poultry production. *Appl. Environ. Microbiol.* **77**, 4273-4279.

Foley, S.L., Lynne, A.M., & Nayak, R. (2008). *Salmonella* challenges: Prevalence in swine and poultry and potential pathogenicity of such isolates. *J. Animal Sci.* **86 (E. Suppl.)**, E149–E162

Galiş¸ A.N., Marcq, C., Marlier, D. Portetelle, D., Van, I., Beckers, Y. & Théwis, A. (2013). Control of *Salmonella* contamination of shell eggs—Preharvest and postharvest methods: A review. *Comp. Revs. Food Sci. Food Safety.* **12**, 155–182.

Gantois, I., Ducatelle, R., Pasmans, F., Haesebrouck, F., Gast, R., Humphrey, T. J., & Van Immerseel, F. (2009). Mechanisms of egg contamination by *Salmonella* Enteritidis. *FEMS Microbiol. Revs.* **33**, 718-738.

Gao, F., Stewart, L. E., Joseph, S. W. & Carr, L. E. (1997). Effectiveness of ultraviolet light irradiation in reducing the numbers of *Salmonella* on eggs and egg belt conveyor materials. *Appl. Engineer. Agric.* **13**, 355–359.

Ge, B., LaFon, P.C., Carter, P.J., McDermott, S.D., Abbott, J., Glenn, A., Ayers,S.L., Friedman, S.L., Paige, J.C., Wagner, D.D., Zhao, S., McDermott, P.F. & Rasmussen, M.A. (2013). Retrospective analysis of *Salmonella*, *Campylobacter*, *Escherichia coli*, and *Enterococcus* in animal feed ingredients. *Foodborne Path. Dis.* **10**, 684-691.

Guard-Petter, J. **(**2001). The chicken, the egg and *Salmonella enteritidis*. *Environ. Microbiol.* **3**, 421–430.

Guinée, J .B. , Heijungs, R., Huppes, G ., Zamagni, A., Masoni, P., Buonamici, R.O., Ekvall, T., & Rydberg, T. (2011) Life cycle assessment: Past, present, and future. *Environ. Sci. Technol.* **45**, 90–96.

Hannah , J.F., Wilson, J.L., Cox, N.A., Cason, J.A., Bourassa, D.V., Musgrove, M.T., Richardson, L.J., Rigsby, L.L., & Buhr, R.J. (2011) Comparison of shell bacteria from unwashed and washed table eggs harvested from caged laying hens and cage-free floor-housed laying hens. *Poultry Sci*. **90**, 1586–1593.

Hanning, I., Nutt, J.D., & Ricke, S.C. (2009). Salmonellosis outbreaks due to fresh produce: Sources and potential intervention measures. *Foodborne Path. Dis.* **6**, 635-648.

Henriques, A., Sereno, R. & Almeida, A. (2013). Reducing *Salmonella* horizontal transmission during egg incubation by phage therapy. *Foodborne Pathogens and Disease. 10*: 718-722.

Henzler, D.J., Kradel, D.C. & Sischo, W.M. (1998). Management and environmental risk factors for *Salmonella enteritidis* contamination of eggs. *Am. J. Vet. Res.* **59**, 824-829.

Henzler, D. J. & Opitz, H. M. (1992). The role of mice in the epizootiology of *Salmonella enteritidis* infection on chicken layer farms. *Avian Dis.* **36**, 625–631.

Higgins, S. E., Higgins, J. P., Wolfenden, A. D. , Henderson, S. N., Torres-Rodriguez, A., Tellez, G., & Hargis, B. (2008). Evaluation of a *Lactobacillus*-based probiotic culture for the reduction of *Salmonella* Enteritidis in neonatal broiler chicks. *Poultry Sci.* **87**, 27–31.

Higgins, S.E., Erf, G.F., Higgins, J.P., Henderson, S.N., Wolfenden, A.D., Gaona-Ramirez, G., & Hargis, B.M. (2007). Effect of probiotic treatment in broiler chicks on intestinal macrophage numbers and phagocytosis of *Salmonella* Enteritidis by abdominal exudate cells. *Poultry Sci.* **86**, 2315–2321.

Hinkle, N.C. & Hickle, L.A. (1999). California caged layer pest management evaluation. *J. Appl. Poultry Res.* **8**, 327-338.

Holt, P. S. (2003). Molting and *Salmonella enterica* serovar enteritidis infection: The problem and some solutions. *Poultry Sci.* **82**,1008–1010.

Holt, P. S. (1999) Chapter 33. Impact of induced molting on immunity and *Salmonella enterica* serovar Enteritidis infection in laying hens. In: *Salmonella enterica serovar Enteritidis in humans and animals—epidemiology, pathogenesis, and control.* A.M. Saeed, R. K. Gast, M. E. Potter, and P. G. Wall, (Eds). (pp 367–375) Ames, IA: Iowa State University Press.

Holt, P. S., Davies, R. H., Dewulf, J., Gast, R. K., Huwe, J. K., Jones, D. R., Waltman, D., & Willian, K. R. (2011). The impact of different housing systems on egg safety and quality. *Poultry Sci.* **90**, 251-262.

Howard, Z.R., O'Bryan, C.A., Crandall, P.G., & Ricke, S.C. (2012). *Salmonella* Enteritidis in shell eggs: Current issues and prospects for control. *Food Res. Int.* **45**, 755-764.

Hume, M.E. (2011). Historic perspective: Prebiotics, probiotics, and other alternatives to antibiotics. *Poultry Sci.* **90**, 2663–2669.

Humphrey, T. J. 1999. Chapter 18. Contamination of eggs and poultry meat with *Salmonella enterica* serovar Enteritidis. In: *Salmonella enterica serovar Enteritidis in humans and animals—epidemiology, pathogenesis, and control.* A.M. Saeed, R. K. Gast, M. E. Potter, and P. G. Wall, (Eds). (pp 183–192) Ames, IA: Iowa State University Press.

Humphrey, T.J. (1994) Contamination of egg shell and contents with *Salmonella enteritidis*: A review. *Int. J. Food Microbiol*. **21**, 31-40.

Hutchison, M.L., Gittins, J., Walker, A., Sparks, N., Humphrey, T.J., Burton, C., & Moore, A. (2004) An assessment of the microbiological risks involved with egg washing under commercial conditions. *J. Food Prot.* **67**, 4–11.

Hutchison, M.L., Gittins, J., Walker, A. Moore, A., Burton, C. & Sparks. (2003). Washing table eggs: A review of the scientific and engineering issues. *World's Poultry Sci. J.* **59**, 233-248.

Ibarburu, M. and Bell, D. (2013). U.S. flock and egg price projections. Report # 47 Egg Industry Center, Iowa State University, Ames, IA.

Jarquin, R., Hanning, I., Ahn, S., & Ricke, S.C. (2009) Development of rapid detection and genetic characterization of *Salmonella* in poultry breeder feeds. *Sensors* **9,** 5308-5323.

Jones, D.R., Anderson, K.E. & Musgrove, M.T. (2011). Comparison of environmental and egg microbiology associated with conventional and free-range laying hen management. *Poultry Sci.* **90**, 2063-2068.

Jones, D.R., Musgrove, M.T., Anderson, K.E, & Thesmar, H.S. (2010). Physical quality and composition of retail shell eggs. *Poultry Sci.* **89**, 582–587.

Jones, D.R. & Musgrove, M.T. (2008a) Identification of *Enterobacteriaceae* on vacuum loaders in shell egg processing. *Poultry Sci.* **87**, 1678–1681.

Jones, D.R. & Musgrove, M.T. (2008b) Assessment of microbial contaminants present on vacuum loaders in shell egg processing facilities. *J. Food Safety* **28,** 346–354.

Jones, D.R., Musgrove, M.T., Caudill, A.B.,& Curtis, P.A. (2006) Frequency of *Salmonella*, *Campylobacter*, *Listeria*, and Enterbacteriaceae detection in commercially cool water-washed shell eggs. *J. Food Safety* **26,** 264–274.

Jones, D.R., Musgrove, M.T., & Northcutt, J.K., (2004) Variations in external and internal microbial populations in shell eggs during extended storage. *J. Food Prot.* **67**, 2657–2660

Jones, D.R., Northcutt, J.K., Musgrove, M.T., Curtis, P.A., Anderson, K.E , Fletcher, D.L. & Cox, N.A. (2003) Survey of shell egg processing plant sanitation programs: Effects on egg contact surfaces. *J. Food Prot.* **66**, 1486–1489.

Jones, F.T. (2011). A review of practical *Salmonella* control measures in animal feed. *J. Appl. Poultry Res.* **20**, 102–113.
Jones, F.T. & Richardson. K.E. (2004). *Salmonella* in commercially manufactured feeds. *Poultry Sci.* **83**, 384–391.
Jones, F.T., Rives, D.V. & Carey, J.B. (1995). *Salmonella* contamination in commercial eggs and an egg production facility. *Poultry Sci.* **74**, 753-757.
Keklik, N.M., Demirci, A., Patterson, P.H., & Puri, V.M. (2010). Pulsed UV light inactivation of *Salmonella* Enteritidis on eggshells and its effects on egg quality. *J. Food Prot.* **73**, 1408-1415.
Kim, J.W. & M.F. Slavik. 1996. Changes in eggshell surface microstructure after washing with cetylpyridinium chloride or trisodium phosphate. J. Food Prot. 59: 859-863.
Kim, W.K., Bloomfield, S.A., Sugiyama, T., & Ricke, S.C. (2012). Concepts and methods for understanding bone metabolism in laying hens. *World's Poultry Sci. J.* **68**, 71-82.
Kinner, J. A., and Moats, W. A. (1981). Effect of temperature, pH, and detergent on survival of bacteria associated with shell eggs. *Poultry Sci.* **60**,761–767.
Klippen, K. (1990). "Egg production and processing" *Dairy, Food and Environmental*
Knape, K.D., Chavez, C., Burgess, R.P., Coufal, C.D., & Carey, J.B. (2002) Comparison of eggshell surface microbial populations for in-line and off-line commercial egg processing facilities. *Poultry Sci.* **81**, 695–698.
Knape, K.D., Carey, J.B., & Ricke, S.C. (2001). Response of foodborne *Salmonella* spp. marker strains inoculated on egg shell surfaces to disinfectants in a commercial egg washer. *J. Environ. Sci. Health Part B-Pesticides, Food Contaminants Agric. Wastes,* **36**, 219-227.
Knape, K.D., Carey, J.B., Burgess, R.P., Kwon, Y.M., & Ricke, S.C. (1999) Comparison of chlorine with an iodine based compound on eggshell surface microbial populations in a commercial egg washer. *J. Food Safety* **19**, 185-194.
Koelkebeck, K.W., Patterson, P.H., Anderson, K.E., Darre, M.J., Carey, J.B., Ahn, D.U., Ernst, R.A. , Kuney, D.R., & Jones, D. (2008) Temperature sequence of eggs from oviposition through distribution: Processing—Part 2. *Poultry Sci.* **87**, 1187–1194.
Koelkebeck, K.W., Bell, D.D., Carey, J.B., Anderson, K.E., & Darre, M.J. (2001). Egg marketing in national supermarkets: Products, packaging, and prices—Part 3. *Poultry Sci*, **80**, 396–400.
Koo, O.K., Sirsat, S.A., Crandall, P.G., & Ricke, S.C. (2012). Physical and chemical control of *Salmonella* in ready-to-eat products. *Agric., Food, & Anal. Bacteriology,* **2**, 56-68.
Kuenzel, W.J. (2003). Neurobiology of molt in avian species. *Poultry Sci.* **82**, 981–991.
Kuney, D.R., Bokahari, S., Bell, D. & Zeidler, G. (1995). Labor costs and the packaging of table eggs 1962-1991. *J. Appl. Poultry Res.* **4,** 94-99.
Kuo, F.L., Carey, J.B., & Ricke, S.C. (1997a) UV irradiation of shell eggs: Effect on populations of aerobes, molds, and inoculated *Salmonella typhimurium*. *Journal of Food Protection, 60*: 639-643.
Kuo, F.L., Kwon, Y.M., Carey, J.B., Hargis, B.M., Krieg, D.P., & Ricke, S.C. (1997b). Reduction of *Salmonella* contamination on chicken egg shells by a peroxidase-catalyzed sanitizer. *J. Food Sci.* **62**, 873-874, 884.
Kuo, F.-L., Ricke, S.C., & Carey, J.B. (1997c) Shell egg sanitation- UV radiation and egg to effectively reduce populations of aerobes, yeasts, and molds. *J. Food Prot.* **60**, 694-697.
Laird, J.M. Bartlett, F.M., & McKellar, R.C. (1991) Survival of *Listeria monocytogenes* in eggwash water. *Int. J. Food Microbiol.* **12**, 115-122.

Lapuz, R., Tani, H. Sasai, K., Shirota, K., Katoh, H. & Baba, E. (2008). The role of roof rats (*Rattus rattus*) in the spread of *Salmonella* Enteritidis and *S.* Infantis contamination in layer farms in eastern Japan. Epidemiol. Infect. **136**, 1235–1243.

La Ragione, R. M., & Woodward, M. J. (2003). Competitive exclusion by *Bacillus subtilis* spores of *Salmonella enterica* serotype Enteritidis and *Clostridium perfringens* in young chickens. *Veterinary Microbiol.* **94**, 245–256.

Lederer, B.E.(1983) Egg carton field tests. *Poultry Sci.* **62**, 990-999.

Leeson, S. & Marcotte, M. (1993). Irradiation of poultry feed I. Microbial status and bird response. *World's J. Poultry Sci.* **49**, 19-33.

Leinonen , I., Williams, A.G., Wiseman, J., Guy, J., & Kyriazakis, I. (2012) Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Egg production systems. *Poultry Sci*. **91**, 26–40.

Maciorowski, K.G., Herrera, P., Jones, F.T., Pillai, S.D., & Ricke, S.C. (2007). Effects of poultry and livestock feed with bacteria and fungi. *Animal Feed Sci. and Technol.* **133**, 109-136.

Maciorowski, K.G., Herrera, P., Jones, F.T., Pillai, S.D., & Ricke, S.C. (2006a). Cultural and immunological detection methods for *Salmonella* spp. in animal feeds- A review. *Veterinary Res. Comm.* **30**, 127-137.

Maciorowski, K.G., Herrera, P., Kundinger, M.M., & Ricke, S.C. (2006b). Animal production and contamination by foodborne *Salmonella*. *J. Consumer Prot. and Food Safety* **1**, 197-209.

Maciorowski, K.G., Pillai, S.D., Jones, F.T. & Ricke, S.C.. (2005). Polymerase chain reaction detection of foodborne *Salmonella* spp. in animal feeds. *Crit. Revs. Microbiol.* **31**, 45-53.

Maciorowski, K.G., Jones, F.T., Pillai, S.D., & Ricke, S.C. (2004). Incidence and control of food-borne *Salmonella* spp. in poultry feeds- A review. *World's Poultry Sci. J.* **60**, 446-457.

Maciorowski, K.G., Pillai, S.D., & Ricke, S.C. (2000). Efficacy of a commercial polymerase chain reaction-based assay for detection of *Salmonella* spp. in animal feeds. *J. Appl. Microbiol.* **89**, 710-718.

Martelli, F. & Davies, R.H. (2012). *Salmonella* serovars isolated from table eggs: An overview. *Food Res. Int.* **45**, 745–754

McKee, S.R., Kwon, Y.M., Carey, J.B., Sams, A.R. & Ricke, S.C. (1998) Comparison of a peroxidase-catalyzed sanitizer with other egg sanitizers using a laboratory-scale sprayer. *J. Food Safety* **18**, 173-183.

McLeod, A., Thieme, O., and Mack, S.D. (2009). Structural changes in the poultry sector: will there be smallholder poultry development in 2030? *World's Journal of Poultry Science, 65*: 191-200.

McReynolds, J.L., Moore, R.W., Kubena, L.F., Byrd, J.A., Woodward, C.L., Nisbet, D.J., & Ricke, S.C. (2006). Effect of various combinations of alfalfa and standard layer diet on susceptibility of laying hens to *Salmonella* Enteritidis during forced molt. *Poultry Sci.* **85**, 1123-1128.

Mellor, D.B., Gardner, F.A., & Campos, E.J. (1975). Effect of type of package and storage temperature on interior quality of shell treated shell eggs. *Poultry Sci.* **54**, 742-746.

Mellor, D.B., & Gardner, F.A. (1975). An evaluation of interior quality of shell eggs packed in the carton while still warm. *Poultry Sci.* **54**, 461-465.

Mellor, D.B., & Gardner, F.A. (1970). The effect of egg cartons on interior quality and breakage of shell eggs. *Poultry Sci.* **49**, 793-798.

Mench , J.A, Sumner, D.A., & Rosen-Molina, J.T. (2011). Sustainability of egg production in the United States—The policy and market context. *Poultry Sci.* **90**, 229–240.

Messens, W. (2011). Chapter 9. Egg decontamination by washing. In: *Improving the safety and quality of eggs and egg products. Volume 2: Egg safety and nutritional quality*, F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.163-180. Woodhead Publishing Limited, Oxford, UK.

Michella, S.M. & Slaugh, B.T. (2000). Producing and marketing a specialty egg. *Poultry Sci.* **79**, 975–976.

Milillo, S.R., Friedly, E.C., Saldivar, J.C., Muthaiyan, A., O'Bryan, C.A., Crandall, P.G., Johnson, M.G., & Ricke, S.C. (2012) A review of the ecology, genomics and stress response of *Listeria innocua* and *Listeria monocytogenes*. *Crit. Reviews in Food Sci. and Nutr.* **52**, 712-725.

Milillo, S.R., Stout, J.C., Hanning, I.B., Clement, A., Fortes, E.D., den Bakker, H.C., Wiedemann, M., & Ricke, S.C. (2012b) Characteristics of *Listeria* from pasture-reared poultry reveals *L. monocytogenes* and hemolytic *L. innocua* in poultry ceca and the pasture environment. *Poultry Sci.* **91**, 2158–2163.

Moats, W. A. 1978. Egg washing—a review. *J. Food Prot.* **41**, 919–925.

Moore, R.W., Park, S.Y., Kubena, L.F., Byrd, J.A., McReynolds, J.L., Burnham, M.R., Hume, M.E., Birkhold, S.G., Nisbet, D.J., Ricke, S.C. (2004). Comparison of zinc acetate and propionate addition on gastrointestinal tract fermentation and susceptibility of laying hens to *Salmonella enteritidis* during forced molt. *Poultry Sci.* **83**, 1276-1286.

Murase, T., Senjyu, K. Maeda, T., Tanaka, M., Sakae, H., Matsumoto, Y., Kaneda, Y., Ito, T. & Otsuki, K. (2001). Monitoring of chicken houses and an attached egg-processing facility in a laying farm for *Salmonella* contamination between 1994 and 1998. *Journal of Food Protection*, **64**, 1912–1916.

Musgrove, M.T. (2011). Chapter 1. Microbiology and safety of table eggs. In: *Improving the safety and quality of eggs and egg products. Volume 2: Egg safety and nutritional quality*, F. Van Immerseel, Y. Nys and M. Bain (Eds.), pp.3-33. Woodhead Publishing Limited, Oxford, UK.

Musgrove, M.T., Shaw, J.D. & Harrison, M.A. (2012) *Salmonella* collected from nest run cart shelves in commercial shell egg processing facilities. *Poultry Sci.* **91**, 2386–2389.

Musgrove, M.T., Jones, D.R., Shaw, J.D., Sheppard, M. & Harrison, M.A. (2009) Enterobacteriaceae and related organisms isolated from nest run cart shelves in commercial shell egg processing facilities. *Poultry Sci.* **88**, 2113–2117.

Musgrove, M.T., Northcutt, J.K., Jones, D.R., Cox, N.A., & Harrison, M.A. (2008) Enterobacteriaceae and related organisms isolated from shell eggs collected during commercial processing. Poultry Sci. **87**, 1211–1218.

Musgrove, M.T., Jones, D.R., Northcutt, J.K., Harrison, M.A., & Cox, N.A. (2005) Impact of commercial processing on the microbiology of shell eggs. *J. Food Prot.* **68**, 2367–2375.

Musgrove, M.T., Jones, D.R., Northcutt, J.K., Curtis, P.A., Anderson, K.E., Fletcher, D.L. & Cox, N.A. (2004) Survey of shell egg processing plant sanitation programs: Effects on non–egg-contact surfaces. *J. Food Prot.* **67**, 2801–2804.

Nethercote, C.H., Boisvenu, C.N., & Fletcher, D.A. (1974). Egg carton tests. *Poultry Sci.* **53**, 311-325.

Nisbet, D.J. (2002). Defined competitive exclusion cultures in the prevention of enteropathogen colonization in poultry and swine. *Antonie van Leeuwenhoek 81*: 481-486.

Nisbet, D. J., Corrier, D. E., Ricke, S. C., Hume, M. E., Byrd II, J. A. & DeLoach, J. R. (1996a) Cecal propionic acid as a biological indicator of the early establishment of a microbial ecosystem inhibitory to *Salmonella* in chicks. *Anaerobe* **2**, 345–350.

Nisbet, D. J., Corrier, D. E., Ricke, S. C., Hume, M. E., Byrd II, J. A. & DeLoach, J. R. (1996b) Maintenance of the biological efficacy in chicks of a cecal competitive-exclusion culture against *Salmonella* by continuous-flow fermentation. *J. Food Prot.* **59**, 1279–1283.

Nisbet, D. J., Ricke, S. C., Scanlan, C. M., Corrier, D. E., Hollister, A. G. & DeLoach, J. R. (1994) Inoculation of broiler chicks with a continuous-flow derived bacterial culture facilitates early native cecal bacterial colonization and increases resistance to *Salmonella typhimurium*. *J. Food Prot.* **57**, 12–15.

Nisbet, D.J., Corrier, D.E., Scanlan, C.M., Hollister, A.G., Beier, R.C., & DeLoach, J.R. (1993). Effect of a defined continuous-flow derived bacterial culture and dietary lactose on Salmonella typhimurium colonization in broiler chickens. *Avian Dis.* **37**, 1017-1025.

North, M. O., and Bell, D. D. (1990). Commercial chicken production manual. 4th ed. Chapman Hall, New York.

Northcutt, J.K., Musgrove, M.T. & Jones, D.R. (2005) Chemical analyses of commercial shell egg wash water. *J. Appl. Poultry Res.* **14**, 289–295.

Olsen, A. R. & Hammack, T. S. (2000). Isolation of *Salmonella* spp. from the housefly, *Musca domestica* L., and the dump fly, *Hydrotaea aenescens* (Wiedemann) (Diptera: Muscidae), at caged-layer houses. *J. Food Prot.* **63**, 958–960.

Painter, J.A., Hoekstra, R.M., Ayers, T., Tauxe, R.V., Braden, C.R., Angulo, F., Angulo, F.J., & Griffin, P.M. (2013). Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998-2008. *Emerg. Infectious Dis.* **19**, 407-415.

Park, C.-M., Hung, Y.-C., Lin, C.-S., and Brackett, R.E. (2005) Efficacy of electrolyzed water in inactivating *Salmonella enteritidis* and *Listeria monocytogenes* on shell eggs. *J. Food Prot*. **68**, 986–990.

Park, S.H., Aydin, M., Khatiwara, A., Dolan, M.C., Gilmore, D.F., Bouldin, J.L., Ahn, S., & Ricke, S.C. (2014). Application of current and emerging rapid detection methodologies for identification of *Salmonella* spp. in poultry and poultry products. *Food Microbiol.* **38**, 250-262.

Park, S.H., Jarquin, R**.,** Hanning, I., Almeida, G., & Ricke, S.C. (2011). Detection of *Salmonella* spp. survival and virulence in poultry feed by targeting the *hilA* gene. *J. Appl. Microbiol.* **111**, 426-432.

Park, S.Y., Woodward, C.L., Kubena, L.F., Nisbet, D.J., Birkhold, S.G. & Ricke, S.C. (2008). Environmental dissemination of foodborne *Salmonella* in preharvest poultry production: Reservoirs, critical factors and research strategies. *Crit. Revs. Environ. Sci. Technol.* **38**, 73-111.

Park, S.Y., Birkhold, S.G., Kubena, L.F., Nisbet, D.J., & Ricke, S.C. (2004a). Review on the role of dietary zinc in poultry nutrition, immunity, and reproduction. *Biol. Trace Element Res.* **101**, 147-163.

Park, S.Y., Birkhold, S.G., Kubena, L.F., Nisbet, D.J., & Ricke, S.C. (2004b). Effects of high zinc diets using zinc propionate on molt induction, organs, and postmolt egg production and quality in laying hens. *Poultry Science, 83*: 24-33.

Park, S.Y., Kim, W.K., Birkhold, S.G., Kubena, L.F., Nisbet D.J., & Ricke, S.C. (2004c). Induced moulting issues and alternative dietary strategies for the egg industry in the

United States. *World's Poultry Sci. J.* **60**, 196-209.
Parkhurst, C.R. & Mountney, G.J. (1988). Poultry and Meat Production. New York, NY: Chapman & Hall.
Patrick, M.E., Adcock, P.M., Gomez, T.M., Altekruse, S.F., Holland, B.H. & Tauxe, R.V. (2004). *Salmonella* Enteritidis infections, United States, 1985–1999. *Emerg. Infect. Dis.* **10**, 1–7.
Patterson, J.A. & Burkholder, K.M.. (2003).Application of prebiotics and probiotics in poultry production. Poultry Science **82**, 627–631.
Patterson, P.H., Koelkebeck, K.W., Anderson, K.E., Darre, M.J., Carey, J.B., Ahn, D.U., Ernst, R.A., Kuney, D.R. & Jones, D.R. (2008). Temperature sequence of eggs from oviposition through distribution: Production—Part 1. *Poultry Sci.* **87**, 1182–1186.
Patterson, P.H., Koelkebeck, K.W., Bell, D.D., Carey, J.B., Anderson, K.E., & Darre, M.J. (2001). Egg marketing in national supermarkets: Specialty eggs—Part 2. *Poultry Sci.* **80**, 390–395.
Pelletier, N. M. Ibarburu, & H. Xin. 2014. Comparison of the environmental footprint of the egg industry in the United States in 1960 and 2010. *Poultry Sci.* **93**, 241–255.
Ragni, L., Berardinelli, A., Vannini, L., Montanari, C., Sirri, F., Guerzoni, M. E., & Guarnieri, A. (2010) Non-thermal atmospheric gas plasma device for surface decontamination of shell eggs. *J. Food Engineering* **100**, 125–132.
Revolledo, L., & Ferreira, A.J.P. (2012). Current perspectives in avian salmonellosis: Vaccines and immune mechanisms of protection. *J. Appl. Poultry Res.* **21,** 418–431.
Revolledo, L., Ferreira, A.J.P. & Mead, G.C. (2006) Prospects in *Salmonella* control: Competitive exclusion, probiotics, and enhancement of avian intestinal immunity. *J. Appl. Poultry Res.* **15**, 341–351.
Ricke, S. C. (2005). Chapter 7 - Ensuring the safety of poultry feed. In: *Food safety control in the poultry industry*, G.C. Mead (Ed.), pp. 174-194, Cambridge, UK: Woodhead Publishing.
Ricke, S.C. (2003a). The gastrointestinal tract ecology of *Salmonella* Enteritidis colonization in molting hens. *Poultry Sci.* **82**, 1003-1007.
Ricke, S.C. (2003b). Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. *Poultry Sci.* **82**, 632-639.
Ricke, S.C., Dunkley, C.S., McReynolds, J.L., Dunkley, K.D., & Nisbet, D.J. (2010). Molting in laying hens and *Salmonella* infection. In: *Dynamics in animal nutrition.* P.J. van der Aar & J. Doppenberg (Eds.) , pp. 135-146. Wageningen, the Netherlands: Wageningen Academic Publishers.
Ricke, S.C., Hererra, P. & Biswas, D. (2012a) Chapter 23. Bacteriophages for potential food safety applications in organic meat production. In: *Organic meat production and processing.* S.C. Ricke, E.J. Van Loo, M.G. Johnson and C.A. O'Bryan (Eds.), pp. 407-424. Wiley Scientific/IFT, New York, NY.
Ricke, S.C., Van Loo, E.J., Johnson, M.G. & O'Bryan, C.A. (Eds.), (2012b) Organic Meat Production and Processing. Wiley Scientific/IFT, New York, NY 444 pp.
Ricke, S.C., Dunkley, C.S., & Durant, J.A. (2013a). A review on development of novel strategies for controlling *Salmonella* Enteritidis colonization in laying hens: Fiber – based molt diets. *Poultry Sci.* **92**, 502–525.
Ricke, S.C. Jones**,** D.R., & Gast, R.K. (2013b). Chapter 46. Eggs and egg products. In: S. Doores, Y. Salfinger, *and* M. L. Tortorello (Eds.), *Compendium of methods for the*

microbiological examinations of foods, 5th Edition. (pp. 1-11). Washington D.C. American Public Health Association.

Ricke, S.C., Khatiwara, A., & Kwon, Y.M. (2013c). Application of microarray analysis of foodborne *Salmonella* in poultry production: A review. *Poultry Science 92*: 2243–2250.

Ricke, S.C., Koo, O.-K., Foley, S., & Nayak, R. (2013d). Chapter 7. *Salmonella*. In: *Guide to foodborne pathogens- 2nd Edition* R. Labbé and S. García (Eds.), pp. 112-137, Oxford, UK: Wiley-Blackwell.

Ricke, S.C. & Pillai, S.D. (1999). Conventional and molecular methods for understanding probiotic bacteria functionality in gastrointestinal tracts. *Crit. Revs. Microbiol.* **25**, 19-38.

Ricke, S.C., Pillai, S.D., Norton, R.A., Maciorowski, K.G. & Jones, F.T. (1998). Applicability of rapid methods for detection of *Salmonella* spp. in poultry feeds: A review. *J. Rapid Meths.Auto. Microbiol.* **6,** 239-258.

Robeson, J., Valencia, M., Retamales, J., & Borie, C. (2011). Stability inside hen eggs of a *Salmonella enterica* serovar Enteritidis bacteriophage. *Electronic J. Biotechnol.* **14**, 1-4.

Rodriguez-Romo & Yousef, A.E. (2005) Inactivation of *Salmonella enterica* serovar Enteritidis on shell eggs by ozone and UV radiation. *J. Food Prot.* **68**, 711–717.

Rossi, M., Nys, Y., Anton, M., Bain., De Ketelaere, B., De Reu, K., Dunn, I., Gautron, J., Hammershøj, M., Hidalgo, A., Meluzzi, A., Mertens, K., Nau, F., & Sirri, F. (2013). Developments in understanding and assessment of egg and egg product quality over the last century. *World's J. Poultry Sci.* **69**, 414-429.

Russell, S.M. (2003). The effect of electrolyzed oxidative water applied using electrostatic spraying on pathogenic and indicator bacteria on the surface of eggs. *Poultry Sci.* **82**, 158-162.

Ryan, L.L., Carey, J.B., & Birkhold, S.G. (1996). Economic impact of the broiler and egg industries in Texas. *J. Appl. Poultry Res.* **8**, 447-451.

Scallan, E., Hoekstra, R.M.., Angulo, F.J., Tauxe, R.V., Widdowson, M-A., Roy, S.L., Jones, J.L., & Griffen P.M. (2011). Foodborne illness acquired in the United States—major pathogens, *Emerg. Infect. Dis.* **17**, 7-15.

Schroeder, C.M., Latimer, H.J., Schlosser, W.D., Golden, N.J., Marks, H.M., Coleman, M.E., Hogue, A.T., Ebel, E.D., Quiring, N.M., Kadry, A.-R. M., & Kauss, J. 2006. Overview and summary of the food safety and inspection service risk assessment for *Salmonella* Enteritidis in shell eggs, 2005. *Foodborne Path. Dis.* **3**, 403-412.

Seo, K.H., Holt, P.S. & Gast, R.K. (2001). Comparison of *Salmonella* Enteritidis infection in hens molted via long-term feed withdrawal versus full-fed wheat middling. *J. Food Prot.* **64**, 1917–1921.

Seydim, A.C. & Dawson, P.L. (1999). Packaging effects on shell egg breakage rates during simulated transportation. *Poultry Sci.* **78**, 148-151.

Shapira, N. (2010). Every egg may have a targeted purpose: toward a differential approach to egg according to composition and functional effect. *World's J. Poultry Sci.* **66,** 271-284.

Singh, S., Yadav, A.S., Singh, S.M., & Bharti, P. (2010) Prevalence of *Salmonella* in chicken eggs collected from poultry farms and marketing channels and their antimicrobial resistance. *Food Res. Int.* **43**, 2027–2030.

Siragusa, G.R. & Ricke, S.C. (2012). Chapter 20. Probiotics as pathogen control agents for organic meat production. In: *Organic meat production and processing*. S.C. Ricke, E.J. Van Loo, M.G. Johnson and C.A. O'Bryan (Eds.), pp. 331-349, New York, NY: Wiley Scientific/IFT.

Soria, M.C., M. A. Soria, M.A., Bueno, D.J., & Colazo, J.L. (2011). A comparative study of culture methods and polymerase chain reaction assay for *Salmonella* detection in poultry feed. *Poultry Sci.* **90**, 2606–2618.

Spricigo, D.A., Bardina, C., Cortés, P., & Llagostera, M. (2013). Use of a bacteriophage cocktail to control *Salmonella* in food and the food industry. *Int. J. Food Microbiol.* **165**, 169–174.

St. Louis, M. E., Morse, D. L., Potter, M. E., DeMelfi, T.M., Guzewich, J. J., Tauxe, R. V. & Blake, P. A. (1988). The emergence of grade A eggs as a major source of *Salmonella enteritidis* infections – new implications for the control of salmonellosis. *The J. Amer. Medical Assoc.* **259**, 2103–2107.

Stocki, S.L., Annett, C.B., Sibley, C.D., McLaws, M., Checkley, S.L., Singh, N., Surette, M.G., & A.P. White (2007). Persistence of *Salmonella* on egg conveyor belts dependent on the belt type but not on the rdar morphotype. *Poultry Sci.* **86**, 2375–2383.

Suresh, T., Hatha, A.A.M., Sreenivasan, D., Sangeetha, N., & Lashmanaperumalsamy, P. (2006))Prevalence and antimicrobial resistance of *Salmonella* enteritidis and other salmonellas in the eggs and egg-storing trays from retails markets of Coimbatore, South India. *Food Microbiol.* **23**, 294–299.

Suppakul, P., Miltz, J. Sonneveld, K. & Bigger, S.W. (2003) Active packaging technologies with an emphasis on antimicrobial packaging and its applications. J. Food Sci. 68, 408-420.

Suslow, T.V., Oria, M.P., Beuchat, L.R. Garrett, E.H., Parish, M.E., Harris, L.J., Farber, J.N. , & Busta, F.F. (2003). Production practices as risk factors in microbial food safety of fresh and fresh-cut produce. *Comp. Revs. Food Sci. Food Safety*. **2 (Supplement)**, 38-77.

Taylor, R.C., Omed, H. & Edwards-Jones, G. (2014). The greenhouse emissions footprint of free-range eggs. *Poultry Sci.* **93**, 231–237.

Thompson, J.E. J. Knutson, J., Ernst, R.A., Kuney, D., Riemann, H., Himathongkham, S., & Zeidler, G. (2000) Rapid cooling of shell eggs. *J. Appl. Poultry Res.* **9**, *258-268.*

Todd, E.C.D. (1996) Risk assessment of use of cracked eggs in Canada. *Int. J. Food Microbiol.* **30**, 125-143.

Upadhyaya, I., Upadhyay, A., Kollanoor-Johny, A., Baskaran, S.A., Mooyottu , S., Darre, M.J., & Venkitanarayanan, K. (2013) Rapid inactivation of *Salmonella* Enteritidis on shell eggs by plant-derived antimicrobials. *Poultry Sci.* **92**, 3228–3235.

Utrarachkij, F., Pornraungwong, S., Siripanichgon, K., Nakajima, C., Suzuki, Y., and Suthienkul, O. (2012) Possible horizontal transmission of *Salmonella* via reusable egg trays in Thailand. *Int. J. Food Microbiol.* **154**, 73–78.

Van der Sluis, W. (2007) More organic poultry and eggs in the U.S. World Poultry **23**, 26-28.

Vilà, B., Fontgibell, A., Badiola, I., Esteve-Garcia, E., Jiménez, G., Castillo, M., and Brufau, J. (2009). Reduction of *Salmonella enterica* var. Enteritidis colonization and invasion by *Bacillus cereus* var. *toyoi* inclusion in poultry feeds . Poultry Science, 88: 975–979.

Wales, A.D., Allen, V.M., & Davies, R.H. (2010). Chemical treatment of animal feed and water for the control of *Salmonella*. *Foodborne Path. Dis.* **7**, 3-15.

Wang, H., & Slavik, M. F. (1998) Bacterial penetration into eggs washed with various chemicals and stored at different temperatures and times. *J. Food Prot.* **61**, 276–279.

Whiting, R.C. & Buchanan, R.L. (1997) Development of a risk assessment model for *Salmonella enteritidis* in pasteurized liquid shell eggs. *Int. J. Food Microbiol.* **36**, 111-125.

Windhorst, H.-W. (2009). Recent patterns of egg production and trade: a status report on a regional basis. *World's J. Poultry Sci.* **65**, 685-708.
Windhorst, H.-W. (2008a). Asia's changing role in the global egg industry – an analysis of past, present and foreseeable future dynamics. *World's J. Poultry Sci.* **64**, 533-552.
Windhorst, H.-W. (2008b). A projection of the regional development of egg production until 2015. *World's J. Poultry Sci.* **64**, 356-376.
Windhorst, H.-W. (2007). Bio-energy production - a threat to the global egg industry? *World's J. Poultry Sci.* **63**, 365-379.
Windhorst, H.-W. (2006). Changes in poultry production and trade worldwide. *World's J. Poultry Sci.* **62**, 585-562.
Woodward, C.L., Kwon, Y.M., Kubena, L.F., Byrd, J.A., Moore, R.W., Nisbet, D.J., & Ricke, S.C. (2005). Reduction of *Salmonella enterica* serovar Enteritidis colonization and invasion by an alfalfa diet during molt in leghorn hens. *Poultry Sci.* **84**, 185-193.
Xin, H., Gates, R.S., Green, A.R., Mitloehner, F.M., Moore Jr., P.A., & Wathes, C.M. (2011) Environmental impacts and sustainability of egg production systems. *Poultry Sci.* **90**, 263–277.
Yousaf, M. & Chaudhry, A.S. (2008). History, changing scenarios and future strategies to induce moulting in laying hens. *World's J. Poultry Sci.* **64**, 65-75.