Cross-contamination and recontamination by *Salmonella* in foods: A review

Elena Carrasco *, Andrés Morales-Rueda, Rosa María García-Gimeno

Department of Food Science and Technology, University of Córdoba, Campus de Excelencia International Agroalimentario ceiA3, Edificio Darwin, Anexo, 14010, Córdoba, Spain

**Abstract**

The presence of *Salmonella* in foodstuffs represents an internationally accepted human health concern. Although *Salmonella* causes many foodborne disease outbreaks, there is little evidence to support cross-contamination as a major contributing factor. However, the paramount importance of preventing cross-contamination and recontamination in assuring the safety of foodstuffs is well known. Sources and factors linked to cross-contamination and recontamination of *Salmonella* in foods are reviewed in detail. Those foods which are not submitted to lethal treatment at the end of processing or which do not receive further treatment in the home deserves special attention. *Salmonella* cross-contamination and recontamination episodes have been connected to the following factors: poor sanitation practices, poor equipment design, and deficient control of ingredients. We also examine potential cross-contamination in the home. Cross-contamination and recontamination events at factory level evidence the difficulty encountered for eradicating this pathogen from the environment and facilities, highlighting the need to reinforce industry preventive control measures such as appropriate and standardized sanitation. Also, at consumer level, Public Health Authorities should install hygiene education programs in order to raise consumer awareness of the risks of cross-contamination in the home and their role in its prevention. Finally, a review on cross-contamination models of *Salmonella* spp. is presented.

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### 1. Introduction

Salmonellosis represents an important foodborne disease that continues to pose a major and unacceptable threat to human public health in both developed and developing countries (European Food Safety Authority (EFSA), 2010). The dynamics of *Salmonella* infection is variable and may also be affected by human lifestyle and behavior, changes in industry, technology, commerce and travel (Foley, Lynne, & Nayak, 2008). *Salmonella* serovars are widespread in nature and can be found in the intestinal tract of all animals species, both domestic and wild (Allerberger et al., 2002) which result in a variety of *Salmonella* infection sources.

Currently, *Salmonella* spp. remains a serious foodborne illness risk worldwide according to data (European Food Safety Authority (EFSA), 2010; FAO/WHO, 2002). Salmonellosis accounted for 131,468 confirmed
human cases in the European Union (EU) in 2008, representing the second most often reported zoonotic disease in humans following campylobacteriosis. Human salmonellosis cases reported in 2008 show a 13.5% decrease from 2007 in the EU. However, several European countries still show a significant increasing trend, proving that continuous efforts for prevention and control are still necessary.

In the EU, serotypes *Salmonella* Enteritidis and *Salmonella* Typhimurium are reported as the two major etiologic agents of salmonellosis that have adapted to humans. In the US, *Salmonella* Enteritidis and Typhimurium represent the two most frequently reported serotypes according to Centers for Disease Control and Prevention (Centers for Disease Control, 2006). The distribution of *Salmonella* serotypes in Australia varies geographically. Thus, while S. Typhimurium was the most commonly reported serovar in 2008, S. Enteritidis was frequently reported as cause of human disease, despite it is not endemic in Australia (Yates, 2011). While S. Enteritidis is mostly implicated in the consumption of poultry and eggs, S. Typhimurium is linked to a range of food-producing animals such as poultry, swine, cattle and sheep. S. Enteritidis was a rare serovar until the mid-1980s when it emerged as a frequent cause of salmonellosis in European countries and across the globe (Cogan & Humphrey, 2003; Poppe, 1999). By the 1990s, S. Enteritidis replaced S. Typhimurium as the most common serotype of salmonellosis isolated from humans in many countries (Angulo & Swerdlow, 1999; Cogan & Humphrey, 2003; Tschape et al., 1999). Australia and New Zealand, however, experienced a relatively higher number of outbreaks due to S. Typhimurium compared to Canada, the US and the EU (Dalton et al., 2004). Previous salmonellosis outbreaks in Canada and the US have been linked to S. Enteritidis (Centers for Disease Control, 2004). The global distribution of food and the continuous movement of people around the world facilitate the spread of this agent, allowing the introduction of emerging *Salmonella* serotypes into importing countries.

In general, salmonellosis is transmitted when *Salmonella* cells are introduced in food preparation areas. Several factors such as multiplication in food due to inadequate storage temperature, insufficient cooking or cross-contamination are often implicated in salmonellosis outbreaks (Ryan, Wall, & Gilbert, 1996; Todd, 1997). The main transmission routes of this pathogen are foods of animal origin contaminated with fecal matter (Haeghebaert et al., 2003; Swartz, 2002). However, consumption of meat from infected animals may also occasionally be a source (Benenson, 1995; Tauxe, 1991).

Some investigations highlight the frequent occurrence of *Salmonella* in meats and meat products (Mead et al., 1999) Overall, meat, poultry and eggs are acknowledged as constant vehicles of *Salmonella* serovars and generally involved in the infectious disease (Capita, Alvarez-Astorga, Alonso-Caldeja, Moreno, & Garcia-Fernandez, 2003; Wilson, 2002). However, a wide range of other foodstuffs such as milk, dairy products, fruits, vegetables, and fishery products can be sources of *Salmonella* infection (Todd, 1997). The incidence of *Salmonella* has been studied in poultry meat in many countries such as the United Kingdom (Plummer & Dodd, 1995), Australia (Fearnley, Raupach, Lagala, & Cameron, 2011), Malaysia (Rusul, Khair, Radu, Cheah, & Yassin, 1996), Greece (Arvanitidou, Tsakris, Sofanou, & Katsouyanopoulos, 1998), Spain (Domínguez, Gómez, & Zumalacárregui, 2001) and Italy (Busani et al., 2005). High prevalence rates have been found in these countries and the serotypes isolated vary geographically with predomination of S. Enteritidis, S. Typhimurium, S. Hadar, S. Newport, S. Virchow and S. Heidelberg. All these studies emphasize the fact that poultry meat represents a major source of this pathogen and therefore, recontamination of cooked poultry should be considered as a major risk factor. However, the importance and the impact of recontamination events are not frequently well-documented in reports and scientific literature. This lack of supporting evidence may be explained by several reasons, such as incomplete insight in to the causes of foodborne diseases, underreporting cases or lack of outbreak investigation (Reij, Den Aantrekker, & ILSI Europe Risk Analysis in Microbiology Task Force, 2004).

The objective of this review is to examine the role of cross-contamination and recontamination of foods by *Salmonella*, the principal factors involved, and the strategies developed for prevention of cross-contamination and recontamination.

2. Importance of cross-contamination and recontamination events

In accordance to Pérez-Rodríguez, Valero, Carrasco, García-Gimeno, and Zuerara (2008), who reviewed bacterial transfer modeling in foods, defined cross-contamination as “a general term which refers to the transfer, direct or indirect, of bacteria or virus from a contaminated product to a non-contaminated product”. Similarly, other terms have been used to describe bacterial transfer, but not in a general sense, such as recontamination, which is defined as contamination of food after it has been submitted to an inactivation process.

According to the World Health Organization (WHO) (1992), 25% of foodborne outbreaks are closely associated with cross-contamination events involving deficient hygiene practices, contaminated equipment, contamination via food handlers, processing, or inadequate storage. Identifying sources of infection frequently proves complicated as accurate data is often difficult to obtain from governments, industries, and also incomplete investigations.

*Salmonella* outbreaks linked to cross-contamination processes have highlighted the importance of these events to identify high-risk foods and practices. Given the high percentage of foodborne outbreaks linked to cross-contamination events, future investigations will suggest possible cross-contamination routes when a *Salmonella* outbreak occurs. Cross-contamination and recontamination information on outbreaks in scientific literature is scant. Review papers on outbreaks remain frequently unpublished as they do not completely fulfill prerequisites such as high number of patients affected, emerging pathogen, unusual serotypes or new food matrices. Outbreaks source attribution cannot be regularly confirmed by food sample investigation due to lack of leftover food matter.

When *Salmonella* survival is allowed under cross-contamination and recontamination conditions, several factors such as inadequate temperatures during food preparation as well as survival through undercooking or food handling scenarios become critical.

The potential risk of *Salmonella* spp. to contaminate sites and surfaces in the household has been studied (Gorman, Bloomfield, & Adley, 2002). These authors emphasize how the preparation of raw food such as fresh chicken may magnify the dissemination of *Salmonella* to hands and food contact surfaces. A significant proportion of cross-contamination scenarios occur in domestic kitchens. In fact, in the Netherlands, Germany, and Spain, more than 50% of reported foodborne outbreaks were observed in the home (Beumer, Bloomfield, Exner, Fara, & Scott, 1998; Scott, 1996). Several authors have demonstrated that *Salmonella* cells from frozen broiler chicken were able to contaminate food preparation areas (De Wit, Brockhuizen, & Kempelmacher, 1979; Roberts, 1972; Van Schotthorst, Huisman, & Van Os, 1978). Similarly, De Boer and Hahne (1990) showed the ease with which salmonellas can be transferred from chicken to utensils, a variety of kitchen surfaces, hands and other foods; from those, *Salmonella* cells were recovered from surfaces up to 6 h after contamination. Bradford, Humphrey, and Lappin-Scott (1997) examined the ability of S. Enteritidis, under sterile and non-sterile conditions, to be cross-contaminated from inoculated eggs droplets to melon and beef and grow on these products at ambient temperature. Consumer awareness of the need to implement Good Hygiene Practices (GHP) is of paramount importance in order to prevent the spread of *Salmonella* cells in food preparation areas.

Researchers are increasingly studying the ability of *Salmonella* to colonize different inert food contact surfaces to form biofilm (Bonafonte et al., 2000; Hood & Zottola, 1997; Joseph, Otta, & Karunasagar, 2001) and its potential to act as a continuous source of bacterial contamination, which may cause post-processing contamination. These investigations
give insight to in the mechanisms underlying biofilm formation, suggesting different strategies for prevention.

3. Cross-contamination and recontamination routes and sources

Cross-contamination and recontamination events linked to *Salmonella* during food processing are reported in literature. Below is a review of sources and routes of potential cross-contamination and recontamination episodes by *Salmonella* spp. linked to different food categories.

3.1. Poultry meat

The association between poultry and *Salmonella* genus has long since been recognized. It was not until the 1960s when the poultry industry started to grow thanks to the application of control measures of pullorum disease and fowl typhoid (Poppe, 2000). Subsequently, an increasing isolation of non-host specific *Salmonella* from poultry products and human cases meant a challenge to identify the origin of the strain involved in human cases. Currently consumption of poultry products remains as a well documented major source of salmonellosis, being undercooking and cross-contamination appointed as recognizable risk events (Palmer et al., 2000; Roberts, 1983).

In Canada, Arsenault, Letelier, Quessy, Normand, and Boullanne (2007) observed that the prevalence of *Salmonella*-positive flocks is around 50%. When poultry flocks are infected at farms, *Salmonella* is carried asymptptomatically in the gastrointestinal tract and can be readily transferred to carcasses through fecal contamination in the abattoir. Further spread of cells may occur easily during processing if carcasses become cross-contaminated. Also, the role of feed ingredients as a source of *Salmonella* in the poultry industry has received great attention (Bailey et al., 2001). Feed products may constitute a great attention (Bailey et al., 2001). Feed products may constitute a significant source of contamination by about 1 log unit. However, the removal of microorganisms from carcasses in the spray process can be insufficient if bacteria are firmly attached to the tissues (Lillard, 1993).

Chilling of poultry carcasses to ≤ 4 °C is supposed to guarantee that no *Salmonella* present will be able to multiply. This step includes immersion in cold water or exposure to cold air either by passing carcasses through an air blast system or holding them in a chilling room. As chill water used for immersion of carcasses is usually replaced, the accumulation of bacteria should be minimal. However, since large numbers of carcasses are packed together in water baths, the chances for cross-contamination are increased. In fact, water chilling is considered a major factor in flock-to-flock transmission of *Salmonella* (James et al., 1992; Lillard, 1990; Sarlin et al., 1998). Cross-contamination may still be possible via air currents and water droplets if carcasses are sprayed during chilling stage (Mead, Allen, Burton, & Corry, 2000).

According to Bloomfield and Scott (1997), cross-contamination risks associated with different locations and surfaces depend not only on the occurrence of likely harmful pathogens, but also on the probability of transfer from those sites. As described by Jackson, Blair, McDowell, Kennedy, and Bolton (2007), food pathogens might survive on refrigerated surfaces and pose a cross-contamination risk. Mattick et al. (2003) also reported that *Salmonella* is able to survive air drying in food for at least 24 h and therefore, when cells are released from perishable foods on cutting boards, they may be viable for long periods of time. Jiménez, Tiburzi, Salsi, Moguilevsky, and Pirovano (2008) studied refrigeration conditions affecting the survival of *Salmonella* Hadar inoculated on chicken skin and investigated the potential of transfer to a plastic cutting board. They defined two scenarios where carcasses were treated or untreated with a decontamination agent to assess the effectiveness of the decontamination process in regards to the reduction of *S*. Hadar at three temperature levels (2 °C, 6 °C and 8 °C) and the likelihood of cross-contamination. They found that *Salmonella* was able to detach from chicken skin and be transferred to cutting board more readily when chicken was treated with acid. Similarly, Nissen, Maugesten, and Lea (2001) observed that growth of *S*. Enteritidis on untreated chicken breasts was not significantly different from the growth on decontaminated chicken, except after 3 days when a considerably higher growth was found on untreated samples. The attachment ability of *Salmonella* has been also associated with the moisture content of meat; when carcasses are still fresh and the moisture of the skin is high, the transferance from carcasses to other surfaces is more marked (De Boer & Hahne, 1990; Dickson, 1990; Jiménez et al., 2008; Kusumaningrum, Riboldi, Hazeleger, & Beumer, 2003).

3.2. Other meats

Poultry, pork, and beef have been identified as common sources for salmonellosis (Bacon, Sofos, Belk, Hyatt, & Smith, 2002; Botteldoorn, Heyndrickx, Rijpens, Grijpspeerdt, & Herman, 2003). In Denmark and Germany, the estimation of salmonellosis associated with consumption of pork has been linked to 15–20% of human cases (Berends, Van Knapen, Mosset, Burt, & Snijders, 1998; Borch, Nesbakken, & Christensen, 1996). At pre-harvest, contaminated feed, water, vectors and other environmental sources linked to swine production have been suggested as potential sources of *Salmonella* (Bailey, 1993; Nayak, Kenney, Kewsani, & Ritz, 2003). Pigs can be infected during transport or waiting period in lairage beforeslaughter. It has been suggested that lairage and the slaughterhouse environment are probably the major source for *Salmonella* infections prior to slaughter (Hurd, McKean, Wesley, & Karriker, 2001; Swanenburg, Urlings, Keuzenkamp, & Snijders, 2001). Once *Salmonella* colonizes the gastrointestinal tract of pigs, carcasses can become contaminated at slaughter, and consequently contaminated raw or undercooked red meats will act as transmission routes for salmonellosis. According to Borch et al. (1996), the main contamination sources of...
pig carcasses are feces, pharynx and stomach, and environmental sources such as contact surfaces and handling.

During slaughter, not only carcasses of infected pigs, but cross-contamination from the environment and other infected animals may occur. Botteldoorn et al. (2003) studied the prevalence of *Salmonella* in swine at the moment of slaughter and observed that the slaughterhouse environment was highly contaminated. These authors estimated that cross-contamination accounted for 29% of the positive carcasses. These results agree with other studies (Berends, Van Knapen, Snijders, & Mossel, 1997; Borch et al., 1996) that observed that cross-contamination accounted for 30% of the entire pork carcass contamination in slaughterhouses. Continuous environmental infection sources may maintain *Salmonella* in slaughterhouses indicating inefficient or poor hygiene practices (Botteldoorn et al., 2003). In regard to risk factors at slaughter associated with the presence of *Salmonella* on hog carcasses, Letellier et al. (2009) underlined the importance of the pre-slaughter and pre-evisceration environment on the final contamination status of carcasses. They observed that cleanliness of the hogs and status of scald water were significant factors associated with *Salmonella* status of the carcasses at the end of the slaughtering process. Genetic characterization and serology used in this study highlighted that particular attention should be paid to herd contamination levels of incoming animals and the pre-evisceration environment.

Once slaughtered, the next steps are manufacturing and preparation and storage at retail. At these levels, three major factors such as handling, time and temperature may significantly influence the microbiological quality of pork meat (Lo Fo Wong et al., 2003). Special care must be considered in order to avoid cross-contamination between products, as large quantities of raw meat of different origin may be handled closely together.

Besides swine, cattle are also known reservoirs of *Salmonella*; ground beef has been implicated in salmonellosis outbreaks (Centers for Disease Control, 2006). Despite *Salmonella* in ground beef has decreased with the implementation of the HACCP system (Ehlen, Barlo, & Naugle, 2006), the risk of transmitting this pathogen through the food chain cannot be disregarded, especially in raw, smoked or lightly cooked meat products. Several investigations have studied the overall occurrence of *Salmonella* in beef samples, showing prevalence rates of 1.1% (Little, Richardson, Owen, De Pinna, & Threlfall, 2008b), 4.2% (Bosilevac, Guerini, Kalchayanand, & Koochmarae, 2009) and 6.0% (Gallegos-Robles et al., 2009). In the US, the Food Safety Inspection Service has suggested that the current prevalence of ground beef is 2.4%. Since standard culturing techniques (which are the most popular) may have a lower level of sensitivity than others methods such as immunomagnetic separation (Barkocy-Gallagher et al., 2003), the prevalence of this pathogen in ground beef may be underestimated.

Additionally, cross-contamination in the kitchen can contribute significantly to salmonellosis incidence. Iordache and Tofan (2008) demonstrated the ease with which two strains of *Salmonella Enteritidis* were able to cross-contaminate beef surfaces from inoculated egg droplets.

The role of cross-contamination in RTE meats should also be regarded. On a global scale, RTE meat products may act as vehicles for foodborne pathogens. Some RTE meat products such as biltong (traditional South African dried and spiced meat made from beef, wild game, or chicken) or jerky (American dried meat product from domestic and wild animals) have been involved in salmonellosis outbreaks (Bokkenheuser, 1963; Centers for Disease Control, 1995; Nesper, Louw, Klein, & Sacks, 1957). Previous studies conducted on other RTE products revealed that factors such as food handlers, aprons, utensils, and work surfaces are potential sites for bacterial contamination (Christison, Lindsay, & von Holy, 2007, 2008; Lues & Van Tonder, 2007). Naidoo and Lindsay (2010) evaluated hygiene of surfaces that come into direct contact with an RTE dried meat product, biltong, and highlighted the importance of such surfaces as potential sites contributing to cross-contamination of the final product at the point of sale. With the aid of molecular DNA sequencing methods the study demonstrated that bacterial strains isolated from biltong and, correspondingly, from cutting utensils were 100% genetically identical. Several studies have linked cutting utensils as sources of contamination of RTE products (Lunden, Autio, & Korkeala, 2002; Pal, Labuza, & Diez-Gonzalez, 2008). Cutting during RTE meat slicing have a significant influence in cross-contamination scenarios since blades are capable of disseminating high numbers of microbial populations with every slice which may include foodborne pathogens such as *Staphylococcus aureus*, *Escherichia coli* or *Salmonella* (Fernane, Morales, Carrasco, & Garcia-Gimeno, 2010; Perez-Rodriguez et al., 2007).

In the production of meat and meat products, numerous attempts to mitigate the risk of salmonellosis have been made. At the farm, AIAO (all-in–all-out) system has been proposed to reduce the risk of cross-contamination between groups of animals; AIAO swine productions consist of keeping animals together in groups where pigs from different groups are not mixed during their stay on the farm. Lo Fo Wong et al. (2003) has reported the importance of controlling feed (e.g. acidification of feed) to reduce or remove *Salmonella* from a herd. During transportation to the abattoir, animals are subjected to stress factors such as overcrowding, long duration of transport, “unfamiliar” pigs, noises, etc., which may result in an increase of number of animals excreting *Salmonella* until arrival at the slaughterhouse (Berends et al., 1997). To reduce the spread of infection during transport, it has been proposed not to mix “unfamiliar” animals and handle them as quietly and gently as possible (Warriss, Brown, Edwards, Anil, & Fordham, 1992). Also, trucks should be thoroughly cleaned and disinfected between transports (Rajkowski, Eben, & Laubach, 1998). In the slaughterhouse, Olsen, Brown, Madsen, and Biggaard (2003) emphasized the importance of the segregation of “clean” and “dirty” processes to reduce the likelihood of cross-contamination and the need to improve the hygiene of the equipment used. During processing, Cason and Hinton (2006) concluded that multistage scaling reduced the likelihood for cross-contamination of *Salmonella*, when compared with a single-tank system. Also, scaling temperature should be set, at least, at 62 °C (Hald, Wingstrand, Swansenburg, von Altrock, & Thorberg, 2003). Water chilling of carcasses is considered a major factor in flock-to-flock transmission of *Salmonella* (Lillard, 1990); a total residual chlorine of 45 to 50 mg/l to keep water free from viable vegetative bacteria has been suggested (Lillard, 1989).

### 3.3. Eggs and egg products

*Salmonella Enteritidis* is primarily linked to consumption of poultry, eggs, and egg-derived products (Hayes, Nylen, Smith, Salmon, & Palmer, 1999; Schmid, Burnens, Baumgartner, & Oberreich, 1996). According to Gast and Beard (1992), fresh laid eggs naturally may contain no more than a few hundred *Salmonella* cells. Prompt refrigeration procedures can prevent the growth of these small populations during storage (Gast, Guraya, Guard, & Holt, 2010). This study demonstrates that once *Salmonella Enteritidis* is introduced into the albu- men, it can reach the yolk and multiply during unrefrigerated storage. Eggs infected with *Salmonella* represent a serious threat to consumers. Further investigation of handling of contaminated eggs is necessary to understand their role in kitchens, even if they are not purposed for raw consumption. For instance, kitchen surfaces and utensils may become contaminated by raw infected eggs and serve as an infection medium to other foodstuffs. In fact, research data has shown that cross-contamination events linked to eggs have resulted in outbreaks. Slinks et al. (2009) described an outbreak (*Salmonella Typhimurium* phase type 197) in a series of restaurants across Brisbane, Australia, in a two-month period. Investigation of these restaurants identified a lack of food hygiene and potential cross-contamination issues. The outbreak was traced back to cracked and dirty eggs. In Australia, Food Safety Standards (Food Standards Code) were developed to provide more effective and nationally uniform food safety legislation. Despite national code prohibit the sale of cracked and dirty eggs for retail or catering, the Food Standards Code did not appear to have
properly protected public health as it allowed the sale of contaminated, cracked, and dirty eggs to restaurants where foods and surfaces were cross-contaminated through food handling. Likewise, a survey conducted after an unusual number of *Salmonella* Enteritidis outbreaks associated with the use of eggs in food service in England and Wales (Little et al., 2008) revealed evidence of inadequate eggs storage and handling practices. The food service sector should be aware of salmonellosis hazards and receive proper training on hygiene practices such as the usage of raw shell eggs, in order to avoid cross-contamination episodes and reduce the risk of salmonellosis.

3.4. Low-moisture foods

*Salmonella* spp. is expected to be present in any raw food product since this pathogen is widely disseminated in nature (e.g., water, soil, plants, and animals). *Salmonella* spp. is able to survive for weeks in water and for years in soil if environmental conditions such as temperature, humidity, and pH are favorable (Todar, 2008). Low water activity (aw) represents a barrier to growth for many vegetative pathogens, including *Salmonella* spp. (Betts, 2007). Processed foods such as powdered milk, chocolate, peanut butter, infant food, and bakery products are characteristically low-aw food products. Epidemiological and environmental data investigations have indicated that cross-contamination plays a major role in the contamination of these products (Smith, Dafnas, El-Khry, Koukoutsis, & El-Khry, 2004). *Salmonella* spp. has the capacity to survive in dry foods and feeds for long periods of time (Hiramatsu, Matsumoto, Sakae, & Miyazaki, 2005; Janning, in't Veld, Notermans, & Kramer, 1994; Juven et al., 1984). Furthermore, it has been reported that the combination of low aw and high fat content of foods might have a synergistic effect on *Salmonella* survival (Shachar & Yaron, 2006). Podolak, Enache, Stone, Black, and Elliott (2010) reviewed several sources and risk factors for contamination, survival, persistence, and heat resistance by *Salmonella* in low-moisture products. Poor sanitation practices, substandard facilities, equipment design, and improper maintenance remain the main causes of *Salmonella* contamination in low-moisture foods. Low-moisture products contaminated by *Salmonella* where recontamination and cross-contamination events have been mostly reported are presented.

Chocolate presents a very low moisture content (<8%) and high fat levels. Several potential sources of *Salmonella* like raw cocoa beans or powdered milk may carry *Salmonella* cells. Although *Salmonella* is not capable of growing in finished chocolate, it is able to survive for long periods of time, representing a significant risk even at low levels in the product. Cross-contamination and recontamination events involving chocolate have been reported. Craven, Mackel, Baine, Barker, and Gangarosa (1975) reported an international outbreak by *Salmonella* Eastbourne linked to contaminated chocolate where cross-contamination by airborne dust was a plausible cause. In 2006, a *Salmonella* Montevideo outbreak linked to chocolate products was attributed to a leaking episode (Food Standards Agency, 2006).

Nut and seed products may be naturally contaminated with *Salmonella* because of the nature of cultivation and/or harvesting processes. A great number of nut and seed products have been recalled due to *Salmonella* contamination (Podolak et al., 2010). Cross-contamination and recontamination due to poor sanitary design and machinery maintenance in peanut products may contribute to *Salmonella* contamination. Also, if ingredients are not adequately handled and/or stored and become contaminated with *Salmonella*, they potentially act as a source of contamination for processed finished products. During a salmonellosis outbreak investigation in US, the FDA declared that raw peanut storage was unsuitable (U.S. Food & Drug Administration, 2009a) and cross-contamination opportunities were plausible. In 2007, investigations of an outbreak of salmonellosis linked to peanut butter, the roof of the factory leaked and the sprinkler system broke down (Funk, 2007).

Spray drying is a method of producing a dry powder from a liquid by rapidly drying by hot gas. Spray drying food applications include milk powder, coffee, tea, eggs, cereal, flavorings, etc. The most important factors that influence the survival of *Salmonella* in spray-dried products are temperature during processing, particle density, fat content and strain variation (Miller, Goepfert, & Amundson, 1972). While spray drying foods, the equipment may influence *Salmonella* contamination as Rowe et al. (1987) indicated in a *Salmonella* Ealing outbreak.

*Salmonella* contamination of oilmeal has been a matter of concern for many years (Sato, 2003). The eradication of *Salmonella* in oilmeal plants is a difficult task since a high probability of spreading contamination from manufacturing to storage areas has been observed and hence, cross-contamination is plausible (Morita, Kitazawa, lida, & Kamata, 2006).

Control of *Salmonella* in low-moisture foods presents several challenges to manufacturers. The Grocery Manufacturers Association (2008) published a guidance document, establishing seven control elements against *Salmonella* contamination: 1) prevent entrance and spread of *Salmonella* in processing facilities; 2) increase the stringency of hygiene practices and controls in the Primary *Salmonella* Control Area; 3) application of hygienic principles to building an equipment design; 4) prevent or reduce growth of *Salmonella* in the facility; 5) establish a raw materials/ingredients control program; 6) validate control measures to inactivate *Salmonella*; and 7) establish procedures for verification of *Salmonella* controls and corrective actions.

3.5. Fresh produce and spices

Vegetables, including cilantro, broccoli, cauliflower, lettuce, and spinach, have also been reported as vehicles of *Salmonella* (Quiroz-Santiago et al., 2009). Fresh tomatoes have been commonly linked to salmonellosis outbreaks in the US (U.S. Food & Drug Administration, 2009b). Rana et al. (2010) examined *Salmonella* cross-contamination during postharvest washing of tomatoes and observed that *Salmonella* could spread from contaminated to un inoculated tomatoes during washing procedures. Fresh herbs and spices are classified into the RTE category (Regulation EC No. 2073/2005). Spices such as clove, oregano, black pepper, and paprika among others, may be exposed to great microbial contamination during harvesting and processing and they are sold without any treatment to reduce contamination. Data from literature shows that *Salmonella* has been isolated in spices (Moreira, Lourencao, Pinto, & Rall, 2009; Pafumi, 1986). Despite the industry having more and more sophisticated control mechanisms available, well-designed equipment systems are not able to combat cross-contamination from poor sourcing, choice, and control of raw materials and ingredients.

Fresh produce may be contaminated during production, harvest, processing, at retail levels or in the kitchen at home. Washing procedure is one of the most studied measures to reduce the level of contamination. Pao, Kelsey, and Long (2009) examined the efficacy of chlorine dioxide during spray washing of tomatoes for preventing *Salmonella enterica* transfer from inoculated roller brushes to fruit and wash runoff, reporting an important reduction of the pathogen (5.0±0.3 log). Rana et al. (2010) designed a washing system of tomatoes to simulate a commercial postharvest washing, showing that the use of higher temperatures (37 °C) during washing lead to lower *Salmonella* uptakes than those observed at 20 °C.

3.6. Milk, dairy and milk products

Several foodborne pathogens have usually been detected in raw milk, including *Salmonella* spp., *Campylobacter* spp., *E. coli*, *Listeria monocytogenes*, and *S. aureus* (Oliveir, Jayarao, & Almeida, 2005). Fecal contamination during milking constitutes a primary route for pathogen transmission. The consumption of raw milk represents a well-
documented issue for human health (Headrick et al., 1998; Lejeune & Rajala-Schultz, 2009). However, increasing number of consumers demand raw milk and/or products made from raw milk and other unprocessed products. According to epidemiological data, it is necessary to consider not only the risk of raw milk consumption, but also the likely episodes of recontamination and cross-contamination that can take place at the industry or home kitchen if milk is not pasteurized or heat-treated. However, pasteurized milk has also been involved in salmonellosis infections and outbreaks, as reported by Olsen et al. (2004). According to these authors, pasteurization was adequate. Nevertheless, microbial testing demonstrated that coliform counts were higher (>100 cfu/mL) than those recommended by Pasteurized Milk Ordinance (10 cfu/mL). Cross-contamination episodes were not identified though they should not be ruled out.

Cheese has been characterized as one of the safest food products by some experts (Johnson, Nelson, & Johnson, 1990); however, since cheese is considered an RTE food product and does not undergo any further treatment before consumption, contamination episodes should be considered. Contaminated raw milk as well as cross-contamination with pathogens such as Salmonella, can be introduced into dairy processing plants and represents a human health risk if unpasteurized milk is used for cheese production (Kousta, Mataragas, Skandamis, & Drosinos, 2010). Cross-contamination of cheese may be originated from starter culture, brine, floor, packaging material, cheese vat, cheese cloth, curd cutting knife, cold room, and production room air (Temelli, Anar, Sen, & Akyuva, 2006). Domínguez et al. (2009) reported a Salmonella outbreak caused by raw-milk cheese containing low contamination levels which had not been detected. Despite there are not reported outbreaks where cheeses cross-contamination is linked to salmonellosis outbreaks, these data suggests that contamination and cross-contamination of cheese may occur, and if ignored or underestimated, the risk of salmonellosis could increase.

3.7. Seafood

Seafood is responsible for a significant amount of foodborne diseases and represents a great concern from a public health perspective. Salmonella is not a component of the normal flora of sea animals, thus contamination of seafood is a result of fecal contamination through polluted water, infected food handlers or cross-contamination during production or transport (Lunestad & Borlaug, 2009). High prevalence is frequently attributed to poor hygienic practices during handling and transportation from landing centers to fish markets. Shrimp is one of the most reported seafoods associated with salmonellosis (Wan Norhana et al., 2010). Certain aspects of cooked shrimp production like cooking procedures aboard fishing vessels, chilling with seawater, and intensive handling and transportation make them susceptible to be contaminated.

Data gathered from studies involving Salmonella contamination in prawns (Hatha, Maqbool, & Kumar, 2003; Heinitz, Ruble, Wagner, & Tatini, 2000; Reilly & Twiddy, 1992) have suggested the likelihood of cross-contamination between raw and cooked products. Wan Norhana, Poole, Deeth, and Dykes (2010) reported various physical control measures, including cooking, refrigeration, irradiation, modified atmosphere packaging (MAP), high-pressure processing (HPP) and high-pressure carbon dioxide.

4. Cross-contamination in food-handling scenarios and retail points

Salmonella can remain viable on food contact surfaces for significant periods, increasing the risk of cross-contamination events between food handlers, food products, and food contact surfaces (De Cesare, Sheldon, Smith, & Jaykus, 2003; Humphrey, Martin, & Whitehead, 1994). The role of food workers in foodborne outbreaks have been clearly demonstrated by several authors (Todd, Greg, Bartleson, & Michaels, 2009). Thus, the transmission and survival of enteric pathogens such as Salmonella in the food processing and preparation environment through humans represent an important risk. Among the different causes of foodborne outbreaks, consumer mishandling of food in household plays an important role. Anderson, Shuster, Hansen, Levy, and Volk (2004) indicated that 25% of reported outbreaks are caused by inadequate consumer handling and food preparation at home. In fact, epidemiological studies have revealed that a significant number of consumers follow unsafe and risky practices during meal preparation (Redmond & Griffith, 2003) and do not implement proper hygienic measures to prevent cross-contamination events (Fischer et al., 2007; Jay, Comar, & Govenlock, 1999). In a survey performed by Klontz, Timbo, Fein, and Levy (1995) about hygiene practices, 25% of respondents were reported to reutilize cutting boards without cleaning after cutting raw meat or chicken. Therefore, it is reasonable to expect a reduction of salmonellosis and other foodborne diseases if consumers would apply safe food-handling practices. Cross-contamination and transfer rates of Salmonella enterica from chicken to lettuce were assessed by Ravishankar, Zhu, and Jaroni (2010) under different food-handling scenarios, with and without washing procedures. The study showed that washing using only water is not enough to remove S. enterica while washing procedures including soap, hot water, and vigorous mechanical scrubbing are suitable to reduce cross-contamination.

Retail point scenarios must be addressed since a wide variety of specialist foods such as RTE products are frequently sold in delicatessen and fast food restaurants, where stainless steel blade retail slicers are commonly used in meal preparations. Most likely underreported at retail levels, cross-contamination scenarios involving equipment and utensils such as boards, knives, and slicers are likely to occur when good hygiene practices are not applied by personnel. Slicing of foodstuffs such as RTE meat products can enhance the risk of cross-contamination by contact with contaminated surfaces. Indeed, not only slicing, but also cutting operations, handling or packaging contributes to increase the risk of cross-contamination. Investigations during a salmonellosis outbreak in 1963 confirmed that the vehicle of infection was a tin of corned beef (Ash, McKendrick, Robertson, & Hughes, 1964). The tin was originally contaminated during processing, but it also contaminated slicing machine and spread the contamination to other RTE meats. The potential risk of transfer of Salmonella in slicing scenarios has not been well assessed thus far. However, the study of these scenarios would provide empirical data to develop guides targeted at retailers and industry on proper slicing practices and cleaning and disinfection procedures to prevent transfer and survival of Salmonella.

The role of shopping bags in cross-contamination events has also been discussed. If not adequately washed between uses, reusable bags create the potential for cross-contamination of foods. For instance, when raw meat products and finished foods are carried in the same bag, either together or between uses, the opportunities for cross-contamination increase. Gerba, Williams, and Sinclair (2010) studied the potential for cross-contamination of various food products by reusable shopping bags and observed that great numbers of bacteria were found in almost all bags and coliform bacteria in half. The study suggested that raw meats or other uncooked food products contaminated bags. E. coli was detected in 12% of bags, demonstrating that reusable bags can be contaminated by enteric microorganisms and they constitute a potential hazard, especially if growth were to be proven in plastic bags. Although Salmonella and other pathogens such as Listeria spp. were not isolated from bags, the risk of finding these organisms in reusable shopping bags should not be ignored. In fact, some studies have demonstrated that children have an increased risk of salmonellosis if they ride in a shopping cart carrying meat products and eating other foods such as fruits or vegetables previously prepared at home (Fullerton et al., 2007; Jones et al., 2006). Handling raw food products during shopping and transport to the home is a route for the transmission of these bacteria. Packaged meats might contaminate the bag since they can leak during transport.
Tennant, and Peters (2001) declared that chicken and chicken packaging is a potential vehicle for the introduction of pathogens in retail and domestic kitchens and, in particular, for the cross-contamination of Salmonella and Campylobacter. The study highlighted that food industry and consumers should be concerned about the potential risk of salmonellosis and campylobacteriosis from contamination of both the external and internal packaging surfaces in addition to the chicken itself. It should also be noted that, once contaminated, bags are frequently assigned to purposes others than carrying groceries, and then, the risk of cross-contamination increases. The study also revealed that consumers rarely wash reusable bags, and bacteria were able to grow when stored in the car trunks. This suggests that it is necessary to make recommendations targeted at consumers in order to reduce the risk of cross-contamination by using reusable shopping bags.

Kitchen surfaces also represent a significant risk of cross-contamination and recontamination events (Redmond & Griffith, 2003). Domestic food contact surfaces appear to play an important role in the transmission of foodborne agents such as Salmonella spp. Researchers currently debate which surface materials pose the greatest risk to consumer health in terms of cross-contamination during food preparation. Accordingly, some studies have underlined the essential paradox of choosing food contact surfaces, i.e. those characteristics that make a surface "easy to clean" may also more likely release foodborne pathogens during common food preparation practices (Moore, Blair, & McDowell, 2007). For instance, cutting boards are commonly perceived as significant fomites in cross-contamination of foodstuffs with foodborne agents. Wooden cutting boards and utensils have been banned for a long time in production sites of meat and poultry foods. Still today, opposition is present in respect to the use of wood instead of plastic during food processing despite the lack of evidence of the presumed better sanitation properties of plastic utensils (Ak, Cliver, & Kaspar, 1994; Carpentier, 1997). In contrast, to date, several publications are in favor of wood, demonstrating that plastic is not empirically better (Boursillon & Rithmüller, 2005; Prechter, Betz, Cerny, Wegener, & Windeisen, 2002;). Nevertheless, it is generally recognized that bacteria are able to penetrate the pores of wood where they are then trapped. While plastic cutting boards can be cleaned in a dishwasher (as well as some specially treated wooden boards), this operation may distribute the pathogen onto other food contact surfaces; in contrast, most small wooden boards can be sterilized in a microwave oven. Cliver (2006) stated that epidemiological studies seem to show that cutting board cleaning habits have a slight influence on the incidence of salmonellosis. Therefore, the use of wooden cutting boards is still controversial. Even though the choice of plastic might improve safety due to better cleaning properties of plastic cutting boards, they are not as significant as often stated. Klonz et al. (1995) reported that 25% of their respondents reused cutting boards after cutting raw meat or chicken without proper cleaning procedures. Redmond and Griffith (2003) observed that 81% of consumers used the same utensils and cutting boards for preparation of both raw and RTE products. Deficiencies in food preparation hygiene such as inadequate cleaning of cutting boards after cutting raw meat and poultry likely play a significant role in contamination by pathogens (De Boer & Hahne, 1990). Cross-contamination and transfer rates of Salmonella enterica from chicken to lettuce under three different food-handling scenarios were evaluated by Ravishankar et al. (2010). Their study revealed that Salmonella was easily transferred from cutting boards and knives to lettuce if utensils were not carefully washed with soap and hot water after cutting chicken and before cutting lettuce. Furthermore, this study showed that merely washing contaminated kitchen utensils was not enough to remove S. enterica. The transfer rate obtained in the scenario 1 of this study was 45%, where cutting board and knife were unwashed after cutting the chicken. Similar results were found by Moore, Sheldon, and Jaykus (2003) who found transfer rates of 36–66% for S. Typhimurium from stainless steel surfaces to lettuce. Although significant amounts of Salmonella cells can be removed during washing, diminishing transfer rates, it may not be effective at eliminating the risk of transfer since current infective dose estimates are as low as 10 cells (Cogan, Slader, Bloomfield, & Humphrey, 2002). Kusumaningrum, Van Asselt, Beumer, and Zwiering (2004) studied cross-contamination of various foodborne pathogens including Salmonella spp. As transfer rates can vary according to the organism, the type of surface and food product, cross-contamination should be assessed on a case-by-case basis.

Therefore, cross-contamination in the home kitchen is particularly important and probably, underestimated. The risk of unsafe food-handling practices and poor hygiene is relatively high, and impossible to control. Consumer food safety education is a key issue for ensuring food safety, despite little attention has been paid to this important last step of the "farm to fork" chain. According to FAO/WHO (2002), undercooking and cross-contamination in the homes represent two general pathways for Salmonella spp. contamination.

5. Biofilm formation and food contact surfaces

Biofilm formation is a well-known bacterial mode of growth and survival which protects bacteria from stressful environmental conditions such as drying and cleaning procedures of food surfaces and environment (Reuter, Mallet, Bruce, & van Vliet, 2010). Cross-contamination linked to raw and processed foods by food contact surfaces has been identified as a potential hazardous event (Barners, Lo, Adams, & Chamberlain, 1999). Salmonella spp. has been recovered from a wide range of food contact surfaces; as commented previously, Salmonella is able to attach to inert surfaces in the food processing environment (Hood & Zottola, 1997; Joseph et al., 2001) and consequently form biofilms (Stepanovic, Circovik, Ranin, & Svabic-Vlahovic, 2004). Once a biofilm is formed, it becomes a source of food contamination in processing lines, representing a serious concern for the food industry.

Most of the food processing industry's surfaces such as machinery, pipelines, and working surfaces are made of stainless steel. This material is traditionally selected in the kitchen for food preparation because of its mechanical strength, corrosion resistance, and longevity (Holah & Thorpe, 1990). Food particles are frequently removed from these surfaces when good hygiene practices are applied, although microorganisms might not be removed if appropriate disinfection procedures are not implemented. Some authors have reported the presence of viable Salmonella spp. on stainless steel surfaces (Kusumaningrum et al., 2003) and other materials commonly found in processing plants such as rubber and polyurethane (Chia, Goulter, McMeekin, Dykes, & Fegan, 2009). Gough and Dodd (1998) showed that Salmonella survived when RTE came into contact with raw contaminated vegetables through cutting boards and stainless steel utensils. Different factors influencing the attachment capacity of Salmonella spp. have been studied. Oliveira, Oliveira, Teixeira, Azeredo, and Oliveira (2007) suggested that attachment is strongly strain dependent and the importance of other factors such as production of polysaccharides should be evaluated. Giaouris and Nychas (2006) demonstrated that increasing the levels of appropriate nutrients also provides the most optimal environment for S. Enteritidis PT 4 to adhere, and subsequently, enhance biofilm formation on stainless steel surfaces.

Slicing has been shown to be a risky factor in cross-contamination events, especially if RTE products are sliced, as blades are able to disseminate high numbers of Salmonella (Fernane et al., 2010). In this sense, improving cleaning and disinfection procedures through hand washing, changing of gloves, and daily sanitation of cutting utensils and display cabinets is essential (Naidoo & Lindsay, 2010).

6. Modeling Salmonella transfer in foods

Cross-contamination and recontamination models have experienced a great development in the last years. Zhao, Zhao, Doyle,
Rubino, and Meng (1998) proposed a model of cross-contamination of *Enterobacter aerogenes* (with attachment characteristics similar to those of *Salmonella* spp.) from raw chicken to cutting board, and from cutting board to vegetables, revealing that from 10^6 cfu/g of *E. aerogenes* inoculated on the chicken, approximately 10^3 cfu/cm² was transferred to the cutting board, and approximately 10^2 to 10^4 of *E. aerogenes* to the vegetables. However, this experience was not modeled mathematically. From now on, by model we will mean mathematical model.

Pérez-Rodríguez et al. (2008) published the state-of-the-art of bacterial transfer phenomenon, including a review of the transfer models developed so far. The most popular models are based on transfer rates, which involve the application of Eq. (1).

\[
N_t = TR / 100 \times N_d
\]

where \( N_t \) is the quantity of cells transferred to the receptor surface; \( TR \) is transfer rate, i.e. the percentage of cells transferred from one surface (donor) to another surface (receptor), and \( N_d \) is the quantity of cells contaminating the donor surface.

Often, transfer rates (TRs) show a large variation as a consequence of the large number of factors involved as well as the errors inherent to microbial collection from surfaces and enumeration techniques. To capture the uncertainty and variability of TR data, normal distribution has been proposed as the most appropriate to describe the log-transformed TR data (Montville, Chen, & Schaffner, 2001; Schaffner, 2003).

Usually, the actual contamination level of surfaces is low, and transfer not necessarily occurs. However, artificial contamination levels in experiments carried out to develop transfer models is high to obtain countable concentrations. Hence, transfer experiments are intended to model non-zero transfer rates, rather than modeling failed bacterial transfers, i.e. 0% transfer. Schaffner (2004) and Yang et al. (2006) applied cross contamination frequency values and TRs to describe microbial prevalence and concentration changes, respectively. Ariza, Mettler, Daudin, and Sanaa (2006) based their compartmental and dynamic cross contamination model on the binomial process of bacterial transfer. This is, assuming that microorganisms are homogeneously distributed in foods, a binomial distribution \( B(n, p) \) could be applied to describe bacterial transfer between different compartments, \( p \) being the transfer probability of a cell and \( n \) the number of bacteria in the compartment. The binomial model can also explain 0% transfer events (prevalence changes) when \( p \) and/or \( n \) become very small.

Moore et al. (2003) approached the cross-contamination phenomenon from stainless steel to lettuce in a similar way as Zhao et al. (1998), although they calculated the transfer rate of *S. Typhimurium* and *Campylobacter jejuni*, showing that *S. Typhimurium* was able to transfer during the first 60 min of contact with a transfer rate (TR) of up to 66%. TR was calculated as follows:

\[
% \text{transfer} = \frac{\text{CFU}_{\text{let}}}{\text{CFU}_{\text{let}} + \text{CFU}_{\text{sst}}} \times 100\%
\]

where CFU_{let} is the number of colony forming units found in lettuce and CFU_{sst} is the number of colony forming units found in stainless steel coupons.

Other authors (Kusumaningrum et al., 2003) have calculated TR differently from Moore et al. (2003). As described above by Pérez-Rodríguez et al. (2008), solving for TR in Eq. (1) we get:

\[
% \text{transfer rate} = \frac{N_t}{N_s} \times 100\%
\]

where \( N_t = \text{CFU recovered from food} \); \( N_s = \text{CFU on surfaces recovered by contact plate} \).

These authors calculated the TR for *S. enteritidis*, *S. aureus* and *C. jejuni* from stainless steel surfaces to food (cucumber and chicken fillet slices). *S. enteritidis* TR data ranged from 105 ± 26% to 50 ± 18% in cucumber slices, and from 94 ± 42% to 32 ± 9% in roasted chicken fillets, depending on the time of recovery of cells (just or 15 min after the cross-contamination event) and the application or not of pressure (the level of pressure applied was 500 g per slice, approximately 20 g/cm², comparable to the pressure applied during sampling with contact plates). In a later stage, Kusumaningrum et al. (2004) carried out a quantitative analysis of cross-contamination of *Salmonella* and *Campylobacter* spp. via domestic kitchen surface, to finally estimate the risk of salmonellosis and campylobacteriosis per serving of salad. In this analysis, they modeled the transfer rate of both microorganisms from chicken carcasses to kitchen surfaces (TR₁) and from kitchen surfaces to salad vegetables (TR₂). In this way, the level of contamination of the pathogen in salad vegetables was given by Eq. (3).

\[
CV = \frac{N \times TR_1/100}{100} \times TR_2/100
\]

where \( CV \) is the level of contamination on salads; \( N \) is the level of microorganisms on contaminated chicken carcasses (CFU/cm² carcass); and \( TR_1 \) and \( TR_2 \) are as above.

The authors found that, for *Salmonella*, the TR₁ mean was 1.6%, while the TR₂ mean was 34.8%. As their quantitative analysis was stochastic, the authors selected normal distributions to describe the log-transformed transfer rates from one surface to another.

Chen, Jackson, Chea, and Schaffner (2001) quantified bacterial cross-contamination rates during common food service tasks; for this, they used *E. aerogenes* as surrogate for *Salmonella*. They calculated TR in an appropriate manner depending on the task evaluated. For instance, to evaluate cross-contamination from chicken to hand, they calculated TR as:

\[
\text{Transfer Rate(%) = (CFU on the Hand/CFU on the Chicken)} \times 100
\]

where CFU = colony forming units.

Then, with TR calculated for all replicate experiments of each task, the authors adjusted probability distributions to TR data, finding others than normal distribution as best fit in accordance to the Kolmogorov-Smirnov test. For example, transfer data from chicken to hand, from cutting board to lettuce and hand washing (reduction rate) obeyed to Beta distribution; Weibull distribution was more adequate for modeling transfer from hand to lettuce and from hand to spigot; lastly, Gamma distribution was the best model for describing the transfer from spigot to clean hand.

Møller, Nauta, Christensen, Dalgaard, and Hansen (2011) presented a cross contamination model of *Salmonella* in pork processing during a small-scale grinding process. After evaluating three models, the goodness-of-fit indices applied (Root Mean sum of Square Errors and Akaike Information Criterion) as well as two validation factors (bias and accuracy factors) indicated that the best model was that assuming two environments inside the grinder: in one of them, food matrix is relatively loosely attached and is responsible for the fast transfer to the minced meat, while in the second matrix the transfer occurs at a slower rate. Fig. 1 is a graphic representation of the model. In this way, after passing five contaminated pork slices (≈10^6 cfu/slice) through the grinder, the subsequent non-contaminated slices were contaminated at a descending rate as they were being grinded, presenting a long “tail” region, similar to the thermal inactivation process.

The developed model satisfactorily predicted the observed behavior of *Salmonella* during its cross-contamination in the grinding of up to 110 pork slices. The proposed model is an important tool to examine the effect of cross-contamination in quantitative microbial risk assessment investigations and might also be applied to various other food processes where cross-contamination is involved.

More research is needed in relation to cross-contamination modeling. Identification and measurement of different factors affecting cross-contamination events are crucial. Different tasks and hygiene practices during food serving operations should be described in detail.
for experimental purposes. The study was designed to evaluate the impact of different environmental conditions on the survival of Salmonella spp. in various foods.

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References

[Insert list of references here]

Fig. 1. Transfer model (5 parameters) of Salmonella Typhimurium DT104 during grinding of pork slices.


