Salmonella (non-typhoidal)

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Salmonella spp. are bacteria that cause salmonellosis, a common form of foodborne illness in humans. Some strains of *Salmonella* generally produce mild symptoms, while other strains cause severe disease and can be fatal. *Salmonella* spp. are carried by a range of domestic and wild animals and birds and have been widely isolated from the environment.

Description of the organism

Salmonella spp. are Gram-negative, non-spore forming rod-shaped bacteria and are members of the family Enterobacteriaceae (Jay et al. 2003). The genus *Salmonella* is divided into two species: *S. enterica* (comprising six subspecies) and *S. bongori*. Over 99% of human *Salmonella* spp. infections are caused by *S. enterica* subsp. *enterica* (Bell and Kyriakides 2002; Crum-Cianflone 2008). Strains of *Salmonella* can be characterised serologically based on the presence and/or absence of O (somatic) and H (flagella) antigens. Phage typing is used to subtype *Salmonella* serotypes. The phage type is determined by the sensitivity of the bacterial cells to the lytic activity of selected bacteriophages (Bell and Kyriakides 2002; Jay et al. 2003).

The formal names used to describe types of *Salmonella* are rather cumbersome, for example *S. enterica* subsp. *enterica* serotype Typhimurium. For practical reasons, the shortened versions of these names are commonly used, such as *S.* Typhimurium (Bell and Kyriakides 2002).

Some *Salmonella* serotypes are host-adapted to individual animal species and may differ vastly in the severity of the disease they cause; others such as *S.* Typhimurium have a broad host range, with an ability to infect a wide range of animals, including humans (Jay et al. 2003; Wallis 2006).

S. Typhi and *S.* Paratyphi are specifically associated with infections in humans, leading to severe disease called enteric fever. *S.* Typhi and *S.* Paratyphi produce clinical syndromes referred to as typhoid and paratyphoid fever, respectively. Enteric fever is rare in developed countries, with the majority of cases associated with overseas travel (Darby and Sheorey 2008). For example, in Australia in 2008, 92.5% of notified cases of typhoid fever reported recent overseas travel (OzFoodNet 2009).

Growth and survival characteristics

Salmonellae have relatively simple nutritional requirements and can survive for long periods of time in foods and other substrates. The growth and survival of *Salmonella* spp. is influenced by a number of factors such as temperature, pH, water activity and the presence of preservatives (refer to Table 1).

The temperature range for growth of *Salmonella* spp. is 5.2–46.2 °C, with the optimal temperature being 35–43 °C (ICMSF 1996). Although freezing can be detrimental to *Salmonella* spp. survival, it does not guarantee destruction of the organism. There is an initial rapid decrease in the number of viable organisms at temperatures close to the freezing point as a result of the freezing damage. However, at lower temperatures *Salmonella* spp. have the ability to survive long term frozen storage (Jay et al. 2003). Strawn and Dayluk (2010) showed that *Salmonella* was able to survive on frozen mangoes and papayas stored at -20 °C for at least 180 days.

Heat resistance of *Salmonella* spp. in food is dependent on the composition, pH and water activity of the food. The heat resistance of *Salmonella* spp. increases as the water activity of the food decreases. Foods which are high in fat and low in moisture, such as chocolate and peanut butter, may have a protective effect against heat. In low pH conditions the heat resistance is reduced (Jay et al. 2003; Shachar and Yaron 2006; Podolak et al. 2010).

Salmonella spp. will grow in a broad pH range of 3.8–9.5, with an optimum pH range for growth of 7–7.5 (ICMSF 1996). The minimum pH at which *Salmonella* spp. can grow is dependent on temperature, presence of salt and nitrite and the type of acid present. Volatile fatty acids are more bactericidal than organic acids such as lactic, citric and acetic acid. Outside the pH range for growth, cells may become inactivated, although this is not immediate and cells have been shown to survive for long periods in acidic products (Bell and Kyriakides 2002; Jay et al. 2003).

Water activity (a_w) has a significant effect on the growth of *Salmonella* spp., with the optimum a_w being 0.99 and the lower limit for growth being 0.93. *Salmonella* spp. can survive for months or even years in foods with a low water activity (such as black pepper, chocolate, peanut butter and gelatine) (ICMSF 1996; Podolak et al. 2010).

Salmonella spp. are similar to other Gram negative bacteria in regard to susceptibility to preservatives commonly used in foods. Growth of *Salmonella* spp. can be inhibited by benzoic acid, sorbic acid or propionic acid. The inhibition of *Salmonella* spp. is enhanced by the use of several preservative factors in combination, such as a preservative in combination with reduced pH and temperature (ICMSF 1996; Banerjee and Sarkar 2004; Ha et al. 2004).

Salmonella spp. are classed as facultative anaerobic organisms as they do not require oxygen for growth (Jay et al. 2003).

Table 1: Limits for growth when other conditions are near optimum (ICMSF 1996; Podolak et al. 2010)

	Minimum	Optimum	Maximum
Temperature (°C)	5.2	35–43	46.2
pH	3.8	7–7.5	9.5
Water activity	0.93	0.99	>0.99

Symptoms of disease

Outcomes of exposure to non-typhoidal *Salmonella* spp. can range from having no effect, to colonisation of the gastrointestinal tract without symptoms of illness (asymptomatic infection), or colonisation with the typical symptoms of acute gastroenteritis. Gastroenteritis symptoms are generally mild and may include abdominal cramps, nausea, diarrhoea, mild fever, vomiting, dehydration, headache and/or prostration. The incubation period is 8–72 hours (usually 24–48 hours) and symptoms last for 2–7 days (WHO/FAO 2002; Darby and Sheorey, 2008). Severe disease, such as septicaemia sometimes occurs, predominantly in immunocompromised individuals. This occurs when *Salmonella* spp. enters the bloodstream, leading to symptoms such as high fever, lethargy, abdomen and chest pain, chills and anorexia, and can be fatal (in less than 1% of cases). A small number of individuals develop a secondary condition such as arthritis, meningitis or pneumonia as a consequence of infection (Hohmann 2001; WHO/FAO 2002; FDA 2009).

Salmonella spp. are shed in large numbers in the faeces of infected individuals at the onset of illness. In the case of non-typhoid disease, bacterial shedding continues for about 4 weeks after illness in adults and 7 weeks in children. In 0.5% of non-typhoid cases individuals become long-term carriers and continue shedding the bacteria on an ongoing basis (Jay et al. 2003; Crum-Cianflone 2008).

Virulence and infectivity

Once ingested, *Salmonella* spp. must survive the low pH of the stomach, adhere to the small intestine epithelial cells and overcome host defence mechanisms to enable infection (Jay et al. 2003).

Salmonella possesses a number of structural and physiological virulence factors enabling it to cause acute and chronic disease in humans. The virulence of *Salmonella* varies with the length and structure of the O side chains of lipopolysaccharide (LPS) molecules at the surface of the cell. Resistance of *Salmonella* to the lytic action of complement (part of the immune response) is directly related to the length of the O side chain (Jay et al. 2003). Other important virulence factors include the presence and type of fimbriae, which is related to the ability of *Salmonella* to attach to epithelium cells, as well as the expression of genes responsible for invasion into cells (Jones 2005). Some of these virulence genes are encoded on *Salmonella* pathogenicity islands (SPI). SPI-1 is required for invasion of the microorganism into intestinal epithelial cells, while systemic infections and intracellular accumulation of *Salmonella* are dependent on the function of SPI-2 (Valle and Guiney 2005).

Salmonella spp. produce a heat labile enterotoxin, resulting in the loss of intestinal fluids (causing diarrhoea). This enterotoxin is closely related functionally, immunologically and genetically to the toxin of *Vibrio cholerae* and the heat labile toxin of pathogenic *E. coli* (Jay et al. 2003). Most *Salmonella* strains also produce heat labile cytotoxin which may cause damage to the intestinal mucosal surface and results in general enteric symptoms and inflammation. Infection with non-typhoidal *Salmonella* is generally limited to a localised intestinal event. However, the presence of virulence plasmids has been associated with non-typhoidal *Salmonella* spp. surviving in phagocytes and spreading from the small intestine to the spleen and liver (Jay et al. 2003; Hanes 2003).

Multiple antibiotic resistant strains of *Salmonella* have emerged, an example being *S.* Typhimurium definitive phage type 104 (DT104). Multi-resistant *S.* Typhimurium DT104 infects both humans and animals, such as cattle and sheep. To date, this organism is not endemic in Australia, although it is a significant health problem in European countries, North America, the Middle East, South Africa and South-East Asia (Jay et al. 2003)

Mode of transmission

Salmonella spp. are transmitted by the faecal-oral route by either person-to-person contact, consumption of contaminated food or water, or from direct contact with infected animals (Jay et al. 2003).

Incidence of illness and outbreak data

Salmonellosis is one of the most commonly reported enteric illnesses worldwide, being the second most frequently reported cause of enteric illness in Australia (behind campylobacteriosis). It is a notifiable disease in all Australian states and territories, with a notification rate in 2008 of 38.9 cases per 100,000 population (8,310 cases). This was similar to the 2003–2007 mean of 40.1 cases per 100,000 population per year (ranging from 35.2–45.2 cases per 100,000 population per year) (OzFoodNet 2009; NNDSS 2010).

The salmonellosis notification rate varied between jurisdictions from 31 cases per 100,000 population in Victoria to 226 cases per 100,000 population in the Northern Territory. Children aged between 0–4 years had the highest notification rate, with 300 cases per 100,000 population reported for 2008 (OzFoodNet 2009). The higher rate of notified cases in this age group may reflect an increased susceptibility upon first exposure, but may also be a result of other factors such as an increased likelihood of exposure and increased likelihood to seek medical care.

The distribution of *Salmonella* serovars in Australia varies geographically, however *S.* Typhimurium was the most commonly reported serovar in 2008, representing 42% of all notified infections. Internationally, *S.* Enteritidis is frequently reported as cause of human illness, however it is not endemic in Australia, with >80% of notified cases reporting recent overseas travel (Greig and Ravel 2009; OzFoodNet 2009)

The notification rate for salmonellosis in New Zealand in 2008 was 31.5 cases per 100,000 population (1,346 cases). This was slightly higher than the 2007 rate of 30.1 cases per 100,000 populations (ESR 2009). In the US 16.92 cases of salmonellosis were notified per 100,000 population in 2008. This was a slight increase from the 2007 rate of 16.03 cases per 100,000 population (CDC 2010a). In the EU the notification rate for salmonellosis was 26.4 cases per 100,000 population in 2008 (ranging from 0–126.8 cases per 100,000 between countries). This was a 13.5% decrease in the number of cases from 2007 (EFSA 2010).

Outbreaks attributed to *Salmonella* spp. have been associated with eggs, poultry, raw meat, milk and dairy products, fresh produce, salad dressing, fruit juice, peanut butter and chocolate (Jay et al. 2003; Montville and Matthews 2005) (refer to Table 2).

Table 2: Selected major foodborne outbreaks associated with *Salmonella* spp. (>50 cases and/or ≥1 fatality)

Year	Serovar	Total no. cases (fatalities)	Food	Country	Comments	Reference
2009-2010	*S.* Montevideo	272	Salami containing red or black pepper	USA	Pepper was added to the salami after the kill step, pepper samples were positive for *S. Montevideo*	(CDC 2010b)
2008	*S.* Montevideo	61	Chicken	USA	Cross contamination of other food items with raw chicken, undercooking of chicken. *S. Montevideo* isolated from raw chicken	(Patel et al. 2010)
2006-2007	*S.* Tennessee	628	Peanut butter	USA	Environmental samples from the plant were positive for *S. Tennessee*	(CDC 2007)
2005-2006	*S.* Oranienburg	126	Alfalfa	Australia	Alfalfa at the production facility were positive for *S. Oranienburg*	(OzFoodNet 2006)
2005	*S.* Typhimurium PT135	63	Eggs used in bakery products	Australia	*S.* Typhimurium PT135 isolated from cream piping bag and bench of bakery. Issues with handling raw eggs, inadequate hygiene practices and cross-contamination. Eggs were dirty (externally) and from the same farm	(Stephens et al. 2007)
2001-2002	*S.* Oranienburg	>439	Chocolate	Germany	The high fat content of chocolate increases the heat resistance of *Salmonella* spp.	(Werber et al. 2005)
1999	*S.* Typhimurium PT135a	507	Unpasteurised fruit juice	Australia	*S.* Typhimurium PT135a was found on the oranges. It was also found in the fungicide tank and wax tank (through which the oranges passed) of the packing shed	(Federal Court of Australia 2003)
1985	*S.* Typhimurium	16,284 (7)	Pasteurised milk	USA	Potential cross-contamination between the unpasteurised milk and pasteurised milk tank	(Ryan et al. 1987; Montville and Matthews 2005)

Occurrence in food

The primary reservoir of *Salmonella* is the intestinal tract of warm and cold-blooded vertebrates, with many animals showing no sign of illness. Unlike diseased animals which can be removed from production and/or treated, these asymptomatic (carrier) animals can shed large numbers of *Salmonella* spp. in their faeces and are therefore an important source of contamination. Faecal shedding of *Salmonella* spp. leads to contamination of the surrounding environment including soil, crops, plants, rivers and lakes. A wide range of foods have been implicated in foodborne salmonellosis, particularly those of animal origin and those foods that have been subject to faecal contamination (ICMSF 1996; Jay et al. 2003).

At the time of slaughter, *Salmonella* infected animals may have high numbers of organisms in their intestines as well as on the outside of the animal (faecal contamination of hides, fleece, skin or feathers) (Bryan and Doyle 1995; Jay et al. 2003). In Australia, *Salmonella* spp. have been isolated from 3% of chilled cattle carcass samples (n=100) (Fegan et al. 2005). The distribution of *Salmonella* spp. on contaminated meat carcasses is not uniform. For example, a US study by Stopforth et al. (2006) found that the prevalence of *Salmonella* spp. on fresh beef ranged from 0.8% (rib eye roll, n=133) to 9.6% (strip loins, n=52) depending on the cut of meat. Cross contamination during processing may also lead to increased prevalence of Salmonella in finished products (Bryan and Doyle 1995).

Salmonella spp. are found in a range of foods. The prevalence of *Salmonella* spp. in bulk tank milk internationally is 0–11.8% (FSANZ 2009a). In shellfish (mussels, clams, oysters and cockles) collected off the coast of Spain, *Salmonella* spp. were detected in 1.8% samples (n=2980) (Martinez-Urtaza et al. 2003). Boughton et al. (2004) isolated *Salmonella* spp. from 2.9% of retail pork sausages samples in Ireland (n=921), and in Spain, *Salmonella* spp. were detected in 2% of cooked ham samples (n=53) and 11.1% of cured dried pork sausage samples (n=81) (Cabedo et al. 2008).

An Australian survey found 43.3% of chicken meat at retail (n=859) was positive for *Salmonella* spp. The most prevalent serovar was *S.* Sofia, with 30.5% of chicken meat samples positive for this serovar (Pointon et al. 2008). Although *S.* Sofia accounts for a large proportion of salmonellae isolated from poultry in Australia it is rarely associated with human or animal illness as it appears to be a non-virulent serovar (Gan et al. 2011). The predominance of *S.* Sofia in poultry is a uniquely Australian observation as *S.* Sofia is essentially geographically isolated to Australia (Mellor et al. 2010).

S. Enteritidis (in particular phage type 4) is a globally important *Salmonella* serotype that can infect the reproductive tract of poultry and contaminate the internal contents of eggs, however, it is not endemic in Australian egg layer flocks (FSANZ 2009b).

Host factors and immunity

People of all ages are susceptible to *Salmonella* spp. infection. However, the elderly, infants and immunocompromised individuals are at a greater risk of infection and generally have more severe symptoms (Jay et al. 2003; FDA 2009).

Dose response

Human feeding trials were undertaken during the 1950s to determine the relationship between the dose of *Salmonella* spp. ingested and the level of illness incurred. These studies showed that ingestion of between 10^5–10^{10} organisms caused infection (McCullough and Eisele 1951a; McCullough and Eisele 1951b; McCullough and Eisele 1951c; McCullough and Eisele 1951d). However, there are a number of limitations on the use of this feeding trial data. Firstly, the volunteers selected were all healthy adult males, so the results may underestimate the risk to the overall population. Secondly, low doses which are more likely to exist in real food contamination events were not considered (Kothary and Babu 2001; Bollaerts et al. 2008). Investigation of salmonellosis outbreaks has estimated dose ranges of <10–10^9 organisms (depending on the food) and as such, doses resulting in illnesses may be much lower than those reported in the feeding trials (Todd et al. 2008).

The WHO/FAO (2002) developed a dose-response model based on outbreak data. Using this model the probability of illness for ingestion of 100 organisms was 1.3×10^{-1}. However, it should be noted that the data used in this model have a certain degree of uncertainty, which required assumptions to be made. This is because it was difficult to determine the actual dose ingested (based on the level of the organism in the food at the time of consumption and the amount of food consumed), as well as determining the actual number of people exposed or ill during the outbreak.

Recommended reading and useful links

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