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Review Article
Salmonella: A foodborne pathogen

[1]Pui, C. F., [1]Wong, W. C., [1]Chai, L. C., [1]Tunung, R., [1]Jeyaletchumi, P., [1]Noor Hidayah, M. S., [1]Ubong, A., [1]Farinazleen, M. G., [2]Cheah, Y. K. and [1*]Son, R.

[1]Center of Excellence for Food Safety Research, Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[2]Department of Biomedical Science, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

Abstract: Salmonellosis continues to be a major public health problem worldwide. It also contributes to negative economic impacts due to the cost of surveillance investigation, treatment and prevention of illness. As such, research on *Salmonella* has gained great interest and concern from scientists. The purpose of this review is to discuss the classification and nomenclature, characteristic, clinical manifestation, epidemiology, transmission vehicles, antibiotic resistance and quorum sensing of *Salmonella*.

Keywords: *Salmonella*, clinical manifestation, epidemiology, transmission, antibiotic resistance, quorum sensing

Introduction

There are 16 million annual cases of typhoid fever, 1.3 billion cases of gastroenteritis and 3 million deaths worldwide due to *Salmonella* (Bhunia, 2008). In brief, *Salmonella* is facultative anaerobe, gram-negative flagellated rod-shaped bacterium which is about 2-3 x 0.4-0.6 µm in size (Yousef and Carlstrom, 2003; Montville and Matthews, 2008).

It is among the most commonly isolated foodborne pathogens associated with fresh fruits and vegetables. In recent years, the incidence of foodborne outbreaks caused by the contamination of fresh fruits and vegetables has increased and become a great concern in industrialized countries. Outbreaks of salmonellosis have been linked to a wide variety of fresh fruits and vegetables including apple, cantaloupe, alfalfa sprout, mango, lettuce, cilantro, unpasteurized orange juice, tomato, melon, celery and parsley (Pui *et al*., 2011b).

Classification and nomenclature

Historically *Salmonella* had been named based on the original places of isolation such as *Salmonella* London and *Salmonella* Indiana. This nomenclature system was replaced by the classification based on the susceptibility of isolates to different selected bacteriophages which is also known as phage typing (Bhunia, 2008). Phage typing is generally employed when the origin and characteristic of an outbreak must be determined by differentiating the isolates of the same serotype. It is very reproducible when international standard sets of typing phages are used. More than 200 definitive phage types (DT) have been reported so far. For example, *S.* Typhimurium DT104 designates a particular phage type for Typhimurium isolates (Hanes, 2003; Andrews and Baumler, 2005).

Epidemiologic classification of *Salmonella* is based on the host preferences. The first group includes host-restricted serotypes that infect only humans such as *S.* Typhi. The second group includes host-adapted serotypes which are associated with one host species but can cause disease in other hosts serotypes such as *S.* Pullorum in avian. The third group includes the remaining serotypes. Typically, *Salmonella* Enteritidis, *Salmonella* Typhimurium and *Salmonella* Heidelberg are the three most frequent serotypes recovered from humans each year (Gray and Fedorka-Cray, 2002; Boyen *et al*., 2008).

Kauffmann-White scheme classifies *Salmonella* according to three major antigenic determinants composed of flagellar H antigens, somatic O antigens and virulence (V_i) capsular K antigens. This was adopted by the International Association of Microbiologists in 1934. Agglutination by antibodies specific for the various O antigens is employed to group Salmonellae into the 6 serogroups: A, B, C1, C2, D and E. For instance, *S.* Paratyphi A, B, C and *S.* Typhi express O antigens of serogroups A, B, C1 and D, respectively. More than 99% of *Salmonella* strains causing human infections belong to *Salmonella enterica* subspecies *enterica*. Although not common, cross-reactivity between O antigens of *Salmonella* and other genera of *Enterobacteriaceae* do occur. Therefore, further classification of serotypes is based

*Corresponding author.
Email: *son@putra.upm.edu.my*
Tel: +603-89468361; Fax: +603-89423552

on the antigenicity of the flagellar H antigens which are highly specific for *Salmonella* (Scherer and Miller, 2001).

In brief, O antigens are lipopolysaccharide (LPS) of the outer bacterial membrane. They are heat stable, resistant to alcohol and dilute acids. H antigens are heat-labile proteins associated with the peritrichous flagella and can be expressed in one of two phases. The phase 1 H antigens are specific and associated with the immunological identity of the particular serovars whereas phase 2 antigens are non-specific antigens containing different antigenic subunit proteins which can be shared by many serovars. K antigens which are heat-sensitive carbohydrates are produced by *Salmonella* serovars that express a surface-bound polysaccharide capsular antigen (Hu and Kopecko, 2003; Yousef and Carlstrom, 2003).

Bacteria can be classified based on phylogeny. A phylogenetic tree can be derived from the comparison with 16S rRNA or other gene sequences. There are 2463 *Salmonella* serotypes which are now placed under 2 species due to the difference in 16S rRNA sequence analysis: *Salmonella enterica* (2443 serotypes) and *Salmonella bongori* (20 serotypes). The system is currently used by World Health Organization (WHO) Collaborating Centre, Centers for Disease Control and Prevention (CDC) and some other organizations. *Salmonella enterica* is further divided into six subspecies, which are designated by roman numerals. *Salmonella enterica* subspecies I is mainly isolated from warm-blooded animals and accounts for more than 99% of clinical isolates whereas remaining subspecies and *S. bongori* are mainly isolated from cold-blooded animals and account for less than 1% of clinical isolates. As an example, the Kauffmann species *Salmonella typhimurium* is now designated as *Salmonella enterica* subspecies I serotype Typhimurium. Under the modern nomenclature system, the subspecies information is often omitted and culture is called *S. enterica* serotype Typhimurium and in subsequent appearance, it is written as *S.* Typhimurium. This system of nomenclature is used nowadays to bring uniformity in reporting (Andrews and Baumler, 2005; Parry, 2006; Bhunia, 2008).

Characteristic

Salmonellae are non-fastidious as they can multiply under various environmental conditions outside the living hosts. They do not require sodium chloride for growth, but can grow in the presence of 0.4 to 4%. Most *Salmonella* serotypes grow at temperature range of 5 to 47°C with optimum temperature of 35 to 37°C but some can grow at temperature as low as 2 to 4°C or as high as 54°C (Gray and Fedorka-Cray, 2002).

They are sensitive to heat and often killed at temperature of 70°C or above. Salmonellae grow in a pH range of 4 to 9 with the optimum between 6.5 and 7.5. They require high water activity (a_w) between 0.99 and 0.94 (pure water a_w=1.0) yet can survive at a_w <0.2 such as in dried foods. Complete inhibition of growth occurs at temperatures <7°C, pH <3.8 or water activity <0.94 (Hanes, 2003; Bhunia, 2008). The comparison of characteristics of *Salmonella* species is indicated in Table 1.

Clinical manifestation

In human disease, the clinical pattern of salmonellosis can be divided into four disease patterns namely enteric fever, gastroenteritis, bacteremia and other complications of nontyphoidal salmonellosis as well as chronic carrier state.

Enteric fever

Salmonella Typhi causes typhoid fever whereas Paratyphi A, B and C cause paratyphoid fever with symptoms which are milder and a mortality rate that is lower for the latter. Both serotypes are solely human pathogens. Infection typically occurs due to ingestion of food or water contaminated with human waste. In recent years, antibiotic-resistant strains have been isolated in most endemic areas, particularly Southeast Asia, India, Pakistan and Middle East (Scherer and Miller, 2001).

Roughly 10% of patients may relapse, die or encounter serious complications such as typhoid encephalopathy, gastrointestinal bleeding and intestinal perforation. Relapse is the most common occurrence probably due to persisting organisms within reticuloendothelial system (RES). Typhoid encephalopathy, often accompanied by shock, is associated with high mortality. Slight gastrointestinal bleeding can be resolved without blood transfusion but in 1 to 2% of cases can be fatal if a large vessel is involved. Intestinal perforation may present with abdominal pain, rising pulse and falling blood pressure in sick people. Hence, it is very serious in 1 to 3% of hospitalized patients (Hu and Kopecko, 2003; Parry, 2006).

Gastroenteritis

Nontyphoidal salmonellosis or enterocolitis is caused by at least 150 *Salmonella* serotypes with *Salmonella* Typhimurium and *Salmonella* Enteritidis being the most common serotypes in the United

Table 1. Comparison of characteristics of *Salmonella* species

Characteristics	*Salmonella enterica* subsp.						*Salmonella bongori*
	enterica	*salamae*	*arizonae*	*diarizonae*	*houtenae*	*indica*	
Classification (roman numeral)	I	II	IIIa	IIIb	IV	VI	V (formerly)
Usual habitat	Warm-blooded animals	Warm-blooded animals	Cold-blooded animals & environment	Cold-blooded animals & environment	Cold-b1ooded animals & environment	Cold-blooded animals & environment	Cold-blooded animals & environment
Morphological characteristics							
Gram stain	-	-	-	-	-	-	-
Motility	+ (except pullorum & gallinarum)	+	+	+	+	+	+
Shape	Rod	Rod	Rod	Rod	Rod	Rod	Rod
Size (width, µm)	0.7-1.5	0.7-1.5	0.7-1.5	0.7-1.5	0.7-1.5	0.7-1.5	0.7-1.5
Size (length, µm)	2-5	2-5	2-5	2-5	2-5	2-5	2-5
Colony morphologies							
Bismuth sulphite agar	Black colonies surrounded by a brown to black zone that casts a metallic sheen						
Eosin-methylene blue agar	Translucent amber to colourless colonies						
Hektoen enteric agar	Blue to blue-green colonies, mostly with black centers (H_2S producers)						
Salmonella-Shigella agar	Colourless colonies on a pink background						
Xylose lysine desoxycholate agar	Black-centered red colonies (H_2S producers)						
Growth characteristics							
Optimum temperature (°C)	35-37	35-37	35-37	35-37	35-37	35-37	35-37
Optimum pH	6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5	6.5-7.5
Biochemical characteristics							
α-glutamyltransferase	d	+	-	+	+	+	+
β-Gluocuronidase	d	d	-	+	-	d	-
Dulcitol	+	+	-	-	-	d	+
Galacturonate	-	+	-	+	+	+	+
Gelatinase	-	+	+	+	+	+	-
Glucose	+	+	+	+	+	+	+
Hydrogen sulfide	+	+	+	+	+	+	+
Indole test	-	-	-	-	-	-	-
Lactose	-	-	-	+	-	+	d
Lysine decarboxylase	+	+	+	+	+	+	+
L(+)-tartrate	+	-	-	-	-	-	-
Malonate	-	+	+	+	-	-	-
Methyl red test	+	+	+	+	+	+	+
Murate	+	+	+	-	-	+	+
Ortho-nitrophenyl-β-D-Galactopyranoside test	-	-	+	+	-	d	+
Phage O1 susceptible	+	+	-	+	-	+	d
Potassium cyanide broth	-	-	-	-	-	-	-
Salicine	-	-	-	+	-	+	d
Sorbitol	+	+	+	+	+	-	+
Urease	-	-	-	-	-	-	-
Voger-Proskauer test	-	-	-	-	-	-	-

Note: +, more than 90% positive reactions; -, less than 10% positive reactions; d, different reactions given by different serovars

States. Infection always occurs via ingestion of water or food contaminated with animal waste rather than human waste. The emergence of multidrug-resistant *S.* Typhimurium DT104 has been associated with outbreaks related to beef contamination and resulted in hospitalization rates twice than that of other foodborne salmonellosis (Gray and Fedorka-Cray, 2002; Yousef and Carlstrom, 2003).

Ciprofloxacin is often administered at the first sign of severe gastroenteritis whereas ceftriaxone is given to children with systemic salmonellosis. In production animals like swine, treatment is usually contraindicated but, when necessary, can be given via injection with several treatment alternatives based on considerations such as withdrawal time. Antibiotic treatment is usually not advised except for rare cases because it can prolong the presence of bacteria in the stool (Gray and Fedorka-Cray, 2002; Yousef and Carlstrom, 2003).

Bacteremia and other complications of nontyphoidal salmonellosis

About 8% of the untreated cases of salmonellosis result in bacteremia. Bacteremia is a serious condition in which bacteria enter the bloodstream after passing through the intestinal barrier. It has been associated with highly invasive serotypes like Cholearaesuis or Dublin. Bacteremia caused by *Salmonella* should be taken into account in cases of fever of unknown origin. Patients with bacteremia and other complications should be treated with antibiotics (Scherer and Miller, 2001; Hanes, 2003).

Chronic carrier state

Salmonellosis can be spread by chronic carriers who potentially infect many individuals, especially those who work in food-related industries. Factors contributing to the chronic carrier state have not been fully explained. On average, nontyphoidal serotypes persist in the gastrointestinal tract from 6 weeks to 3 months, depending on the serotypes. Only about 0.1% of nontyphoidal *Salmonella* cases are shed in stool samples for periods exceeding 1 year. About 2 to 5% of untreated typhoid infections result in a chronic carrier state. Up to 10% of untreated convalescent typhoid cases will excrete *S.* Typhi in feces for 1 to 3 months and between 1 and 4% become chronic carriers excreting the microorganism for more than one year (Scherer and Miller, 2001; Parry, 2006).

Epidemiology

Typhoid cases are stable with low numbers in developed countries, but nontyphoidal salmonellosis has increased worldwide. Typhoid fever usually causes mortality in 5 to 30% of typhoid-infected individual in the developing world. The World Health Organization (WHO) estimates 16 to 17 million cases occur annually, resulting in about 600,000 deaths. The mortality rates differ from region to region, but can be as high as 5 to 7% despite the use of appropriate antibiotic treatment. On the other hand, nontyphoidal cases account for 1.3 billion cases with 3 million deaths. In the United States, approximately 2 to 4 million cases of *Salmonella* gastroenteritis occur with about 500 deaths per year. A more accurate figure of salmonellosis is difficult to determine because normally only large outbreaks are investigated whereas sporadic cases are under-reported. Data on salmonellosis are scarce in many countries of Asia, Africa and South and Central America where only 1 to 10% of cases are reported (Portillo, 2000; Hanes, 2003; Hu and Kopecko, 2003). Some of the incidence, notification and isolation rate of salmonellosis in different part of the world is shown in Figure 1.

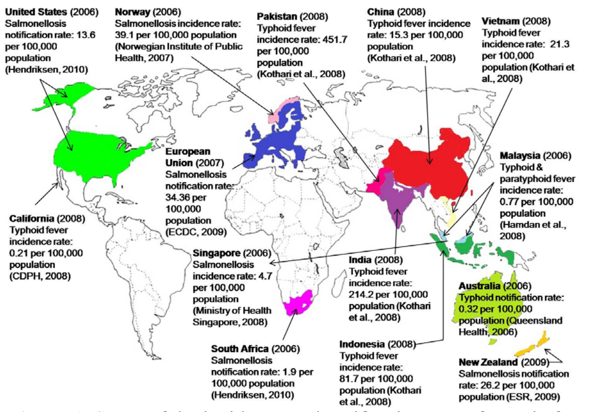

Figure 1. Some of the incidence and notification rate of enteric fever and sallmonellosis in different parts of the world

Typhoid fever is endemic throughout Africa and Asia as well as persists in the Middle East, some eastern and southern European countries and central and South America. In the US and most of Europe, typhoid is predominantly a disease of the returning traveler. Typhoid incidence in endemic areas is typically low in the first few years of life, peaking in school-aged children and young adults and then falling in middle age. Most infections occur in childhood especially in Mekong Delta region of Vietnam and are recognizable although often mild. The most famous outbreak of enteric fever is Typhoid Mary. Mary Mallon, a New York City hired household cook, transmitted typhoid fever to at least 22 individuals causing 3 deaths between 1900 and 1907. After being apprehended by public health officials in 1907, she was isolated for 3 years. Even though she was released with the stipulation that she never cook again, she broke the promise and consequently caused at least 25 more cases of typhoid fever at Manhattan maternity hospital when she was employed as a cook in 1915. She was finally isolated until her death in 1938 (Scherer and Miller, 2001; Parry, 2006) .

The infectious dose of *Salmonella* depends upon the serovar, bacteria strain, growth condition and host susceptibility. On the other hand, host factors controlling susceptibility to infection include the condition of the intestinal tract, age and underlying illnesses or immune deficiencies. The infectious dose of *Salmonella* is broad varying from 1 to 10^9 cfu/g. However, single-food-source outbreaks indicate that as little as 1 to 10 cells can cause salmonellosis with more susceptibility to infection by YOPI groups (Yousef and Carlstrom, 2003; Bhunia, 2008).

Transmission vehicles

Salmonella are widely distributed in nature and they survive well in a variety of foods. Poultry, eggs and dairy products are the most common vehicles of salmonellosis. In recent years, fresh produce like fruits and vegetables have gained concern as vehicles of transmission where contamination can occur at multiple steps along the food chain (Bouchrif *et al*., 2009).

First, environment contaminated with *Salmonella* serves as the infection source because *Salmonella* can survive in the environment for a long time. After that, *Salmonella* is transmitted to vectors such as rats, flies and birds where *Salmonella* can shed in their faeces for weeks and even months. Following the direct transmission, moving animals such as swines, cows and chickens act as the important risk factor for infection. These animal reservoirs are infected orally because *Salmonella* normally originates from the contaminated environment and also contaminated feed. Human get infected when eating the food or drinking the water that is contaminated with *Salmonella* through animal reservoirs. However, *Salmonella* Typhi and *Salmonella* Paratyphi A do not have animal reservoir, therefore infection can be happened by eating the improperly handled food by infected individuals (Newell *et al*., 2010).

Besides, transmission of *Salmonella* to the food processing plants and equipments for food preparation are also of great importance. Once carried by vectors or transferred to food, consumption by human can result in the risk of salmonellosis. The *Salmonella* cells can attach to food contact surfaces such as plastic cutting board which may develop into biofilm once attached and hence cause cross-contamination. Consequently, *Salmonella* can enter the food chain at any point from livestock feed, through food manufacturing, processing and retailing as well as catering and food preparation in the home (Wong *et* *al*., 2002).

The main food involved in salmonellosis is shown in Table 2. Disease surveillance reports frequently identify poultry (chickens, turkeys, geese and ducks) as the main vehicles in the salmonellosis outbreak. *Salmonella* Pullorum and *Salmonella* Gallinarum usually cause disease in poultry. Cox and Pavic (2010) provided extensive overview on poultry meat production associated with *Salmonella* and discussed the approaches for the control of this pathogen throughout the whole production chain as poultry can be contaminated from breeder flocks, hatchery environment, feed and litter as well as water troughs in the pens. In Malaysia, Arumugaswamy *et al*. (1995) reported 39.4% chicken portions, 35.3% chicken liver and 44.4% chicken gizzard were contaminated with *Salmonella* spp.

Table 2. Examples of reported salmonellosis outbreak

Year	Country	Source	Serotype	Number of cases	Reference
2010	United States	Black and red pepper	Montevideo	272	CDC, 2010
2010	United States	Frozen mamey fruit pulp	Typhi	9	CDC, 2010
2010	United States	Shell eggs	Enteritidis	2,752	CDC, 2010
2009	United States	Alfalfa sprouts	Saintpaul	235	CDC, 2010
2008	United States	Cereal from Malt-O-Meal	Agona	28	CDC, 2010
2007	United States	Dry pet food	Schwarzengrund	62	CDC, 2010
2006	United States	Peanut butter	Tennessee	>288	Montville and Matthews, 2008
2005	Austria	Mixed salad	Enteritidis PT21	85	D'Aoust and Maurer, 2007
2005	England	Kebab	Enteritidis PT1	195	D'Aoust and Maurer, 2007
2005	The Netherlands	Imported raw beef	Typhimurium PT104	165	D'Aoust and Maurer, 2007
2005	Malaysia	Stall food	Typhi	171	Nik and Sharifah, 2005
2004	China	Cake/raw egg topping	Enteritidis	197	D'Aoust and Maurer, 2007
2004	Great Britain	Lettuce	Newport	>350	Montville and Matthews, 2008
2003	Germany	Aniseed herbal tea	Agona	42	D'Aoust and Maurer, 2007
2001	Canada, Australia	Shandong peanuts	Stanley	93	D'Aoust and Maurer, 2007
2001	Norway, Sweden	Fish	Livingstone	60	D'Aoust and Maurer, 2007
2000	Singapore	Dried anchovy	Typhimurium DT104L	33	Ling *et al*., 2002
1999	Japan	Dried squid	*Salmonella* spp.	<453	Montville and Matthews, 2008
1996	France	Mont D'or cheese	*Salmonella* spp.	14	Colak *et al*., 2007
1994	Switzerland	Potato salad prepared by carrier	Typhi	10	Gruner *et al*., 1997

Apart from that, *Salmonella* can enter eggs from the oviduct (particularly ducks). Penetration into the egg is increased when the cuticle is damaged, outside of the egg is wet, temperature is decreased and specific gravity of the shell is low. Contamination of eggs and particularly egg contents by *S.* Enteritidis are believed to be a cause of the large outbreak in Europe and North America since 1980s (Jay *et al*., 1997; Bhunia, 2008). Recently, the US Centers for Disease Control and Prevention (CDC) mentioned that there were approximately 1469 illnesses associated with eggs infected by *Salmonella* Enteritidis reported in California, Colorado and Minnesota from May 1 to August 31, 2010. On the other hand, *Salmonella* Infantis was the predominant serotype in Australian egg industry (Cox *et al*., 2002).

Spread of *Salmonella* may be facilitated in water storage tanks in a building, from wild animal feces or even from carcasses. Poor sanitation, improper sewage disposal and lack of clean water system cause the transmission of typhoid fever. In areas where typhoid fever is endemic, water from lakes or rivers which are used for public consumption and are sometimes contaminated by raw sewage are the main sources of infection. The consumption of unboiled water during 1997 typhoid outbreak in Dushanbe, Tajikistan caused 2200 cases of illness and 95 deaths. *Salmonella* contamination of fresh produce could be due to the entry of *Salmonella* through scar tissues, entrapment during embryogenesis of produce, natural uptake through root systems and transfer onto edible plant tissues during slicing. The human health risk is increased further by *Salmonella* preference to grow on fresh produce during retail display at ambient temperature. In 2000, cantaloupe from Mexico resulted in a *Salmonella* Poona outbreak in USA (Penteado and Leitão, 2004; Bordini *et al*., 2007). Table 3 indicated some of studies of the transmission vehicles related to *Salmonella* spp.

Antibiotic resistance

The resistance of *Salmonella* to a single antibiotic was first reported in the early 1960s (Montville and Matthews, 2008). Since then, the isolation frequency of *Salmonella* strains resistant to one or more antibiotics have increased in the Saudi Arabia, United States, United Kingdom and other countries of the world. This is due to the increased and uncontrolled use as well as easy accessibility to antibiotics in many countries of the world (Grob *et al*., 1998; Yoke-Kqueen *et al*., 2007). Emerging resistance in *Salmonella* Typhi has been described especially in Africa and Asia and the appearance of *Salmonella* Typhimurium DT104 in the late 1980s raised main public health concern, thereby threatening the lives of infected individuals (Grob *et al*., 1998; Montville and Matthews, 2008). Van *et al*. (2007) stated that multi-resistance occurred in *Salmonella* serotypes including Albany, Anatum, Havana, London and Typhimurium.

The resistance towards the traditional first-line antibiotics such as ampicillin, chloramphenicol and trimethoprim-sulfamethoxazole define multidrug resistance (MDR) in *Salmonella enterica* (Crump and Mintz, 2010). This is of great concern because majority infections with MDR *Salmonella* are acquired through the consumption of contaminated foods of animal origin such as swines and chicken

Table 3. Prevalence of *Salmonella* spp. from different sources

Country	Sample/source	Prevalence	Predominant serotypes	Reference
Iran	chicken	86/190 (45.3%)	Thompson	Dallal *et al*., 2010
	beef	38/189 (20.1%)		
Brazil	poultry carcass	0/127 (0%)	Enteritidis	Freitas *et al*., 2010
	poultry viscera	2/73 (2.7%)		
Spain	pig	43/804 (5.3%)	Anatum, Typhimurium	Gomez-Laguna *et al*., 2010
	herd	22/67 (32.8%)		
China	chicken	276/515 (53.6%)	Enteritidis, Typhimurium, Shubra, Indiana, Derby, Djugu	Yang *et al*., 2010
	pork	28/91 (30.8%)		
	beef	13/78 (16.7%)		
	lamb	16/80 (20%)		
Morocco	slaughter house	75/105 (71.4%)	Infantis, Bredeney, Blokley, Typhimurium, Mbandaka, Branderup II, Kiambu	Bouchrif *et al*., 2009
	seafood	10/105 (9.5%)		
Bangladesh	chick egg	4/80 (5%)	Typhimurium	Hasan *et al*., 2009
Republic of Ireland	retail pork	13/500 (2.6%)	Typhimurium	Prendergast *et al*., 2009
Turkey	chicken part	1/168 (0.6%)	Infantis	Cetinkaya *et al*., 2008
	minced meat	0/45 (0%)		
	ready-to-eat salad	0/100 (0%)		
	raw vegetable	0/78 (0%)		
	raw milk	0/25 (0%)		
Iran	raw poultry	24/134 (17.9%)	Enteritidis, Baibouknown	Jalali *et al*., 2008
	cooked poultry	3/56 (5.4%)		
	raw meat	8/101 (7.9%)		
	cooked meat	2/118 (1.7%)		
	turkey	1/3 (33.3%)		
	quail	2/5 (40%)		
	vegetable	3/38 (7.9%)		
Lithuania	faeces	28/85 (32.9%)	Enteritidis, Typhimurium	Pieskus *et al*., 2008
	caecum	12/52 (23.1%)		
	dust	5/34 (14.7%)		
	water	1/10 (10%)		
Turkey	tulum cheese	6/250 (2.4%)	-	Colak *et al*., 2007
Vietnam	pork	32/50 (64%)	London, Havana, Anatum, Hadar, Albany, Typhimurium	Van *et al*., 2007
	beef	31/50 (62%)		
	chicken	16/30 (53.3%)		
	shellfish	9/50 (18%)		
Malaysia	street food	12/129 (9.3%)	Biafra, Braenderup, Weltevreden	Tunung *et al*., 2007
	fried chicken	1/18 (5.6%)		
	kerabu jantung pisang	3/5 (60.0%)		
	sambal fish	6/9 (66.7%)		
	mix vegetable	2/5 (40.0%)		
Brazil	chicken abattoir	29/288 (10.1%)	Enteritidis, Typhimurium	Cortez *et al*., 2006
South India	egg	38/492 (7.7%)	Enteritidis	Suresh *et al*., 2006
Jordan	chicken, meat	25/93 (26.9%)	Enteritidis, Typhimurium	Malkawi and Gharaibeh, 2004
Malaysia	selom	16/43 (37.2%)	Weltevreden, Agona, Senftenberg, Albany	Salleh *et al*., 2003
	pegaga	8/26 (30.8%)		
	kangkong	8/25 (32%)		
	kesum	8/18 (44.4%)		
Albania	chicken meat sample	30/461 (6.5%)	Enteritidis	Beli *et al*., 2001
India	fish	104/730 (14.3%)	Weltevreden, Typhi, Paratyphi B, Mgulani, Typhimurium	Hatha and Lakshamanaperumalsamy, 1997
	crustacean	48/276 (17.4%)		
Malaysia	retail poultry	158/445 (35.5%)	Enteritidis, Muenchen, Kentucky, Blockley	Rusul *et al*. , 1996
	litter	8/40 (20.0%)		
	poultry farm	2/10 (20.0%)		
Malaysia	chicken portion	13/33 (39.4%)	Blockley, Enteritidis, Chincol, Muenchen, Agona	Arumugaswamy *et al*., 1995
	chicken liver	6/17 (35.3%)		
	chicken gizzard	8/18 (44.4%)		
	cooked meat, chicken, vegetable	4/28 (14.3%)		
	satay	14/60 (23.3%)		
	prawn	4/16 (25%)		
	oriental shrimp paste	2/19 (10.5%)		

eggs. Asai *et al*. (2010) mentioned that cephalosporin- and fluoroquinone-resistant strains of *S.* Choleraesuis have been identified in swines in Taiwan and Thailand. Apart from that, antibiogram testing by Singh *et al.* (2010) revealed *Salmonella* isolates from chicken eggs in marketing channels and poultry farms in North India were resistant to bacitracin, colistin and polymyxin-B.

Due to the use of antibiotics for the promotion of growth and prevention of disease in food animals, there is an increase of human salmonellosis cases caused by foodborne MDR *Salmonella* nowadays (Yang *et al*., 2010). This indiscriminate and injudicious use of antibiotics in any setting especially in food animals worldwide should be monitored to reduce the transfer risk of MDR *Salmonella* to humans (Zhao *et al*., 2003). Finally, there is a need of continuous surveillance and sharing of antimicrobial susceptibility data for *Salmonella* among countries worldwide (de Oliveira *et al*., 2010) to ensure the effectiveness of control programmes.

Quorum sensing

Quorum sensing, also known as cell-to-cell communication, is the mechanism that involves the bacteria synthesis, secretion and detection of hormone-like molecules known as autoinducers (Elvers and Park, 2002; Reading and Sperandio, 2006). Once the signal molecule achieves the critical threshold concentration, bacteria sense its presence and start the signalling cascade which results in the changes of target gene expression (Gobbetti *et al*., 2007). Traits under quorum-sensing control include antibiotic biosynthesis, extracellular polymer production, biosurfactant synthesis, bioluminescence, sporulation, surface attachment as well as secretion of nutrient sequestering compounds and virulence factors (Nadell *et al*., 2008). An example of the traits under quorum sensing is biofilm formation by *Salmonella* Typhi and *Salmonella* Typhimurium on plastic cutting board as reported by Pui *et al*. (2011a).

Quorum sensing in *Salmonella* involves LuxS/AI-2 system which is the most widespread quorum sensing system. Jimenez-Gomez *et al*. (2007)

considered acyl-homoserine lactone (AHL) as the most important cell-to-cell communication system in *Salmonella*. At low cell densities, it diffuses out of the cells passively down the concentration gradient. On the other hand, at high cell densities, it accumulates at an intracellular concentration equivalent to the extracellular level (Gobbetti *et al*., 2007). *Salmonella* does not produce AHL but has a LuxR homolog, SdiA produced by other bacteria species (Kievit & Iglewski, 2000). The regulatory protein, SdiA regulates some genes in *Salmonella* such as the *rck* gene involved in resistance to human complement, as well as activates the SPI-1 genes and other genes that play role in the virulence (Walters and Sperandio, 2006).

It is the enzyme LuxS which takes part in the metabolism of S-adenosylmethionine (SAM) to produce the by-product, AI-2. Lsr (LuxS-regulated) is the only gene regulated by AI-2 which encodes for ABC transporter in *Salmonella* Typhimurium. Upon the entry to the cell, AI-2 is modified by phosphorylation (Walters and Sperandio, 2006). This AI-2 can then be used to determine the cell population density. It has the advantage of usage for interspecies cell-to-cell communication as compared to all other autoinducers (Xavier and Bassler, 2003).

Conclusion

The issues of food safety attract more attention from the government and public worldwide in recent years. The incidence of salmonellosis outbreak cannot be neglected due to the overwhelming effects to human. The knowledge about *Salmonella* and its evolution is important to ensure the safety and quality of food. Intervention strategies are hence important to control *Salmonella* from farm to fork.

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