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Salmonella in Fish and Fishery Products

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1. Introduction

With more than 30.000 known species, fish form the biggest group in the animal kingdom that is used for the production of animal-based foods. About 700 of these species are commercially fished and used for food production. Further, some 100 crustacean and 100 molluscan species (for example mussels, snails and cephalopods) are processed as food for humans in fish industry (Oehlenschläger & Rehbein, 2009). However, some fishery product is processed in a modern fish industry which is a technologically advanced and complicated industry in line with any other food industry, and with the same risk of product being contaminated with pathogenic organisms (Huss, 1994).

The vast majority of outbreaks of food-related illness are due to pathogenic microorganisms, rather than to chemical or physical contaminants. As they are generally undetectable by the unaided human senses (i.e.they do not usually cause colour changes or produce off-flavours or taints in the food) and they are capable of rapid growth under favourable storage conditions (Lelieveld et al. 2003). The United States Centers for Disease Control and Prevention reported that fish and shellfish account for 5% of the individual cases and 10% of all foodborne illness outbreaks, with most of the outbreaks resulting from the consumption of raw molluscan shellfish (Flick, 2008).

Salmonella is responsible for more than 40.000 cases of food-borne illness every year. The incidence of *Salmonella* infections has risen dramatically since the 1980s, leading to high medical costs, a loss of wages for workers who become ill, and a loss of productivity for the companies whose workers do become ill. In all, these financial losses can cost more than $3.6 billion each year. *Salmonella* infections have long been a concern to scientists, doctors, and the U.S. Food and Drug Administration (FDA) (Brands, 2006). *Salmonella* is causing a public health problem associated with fish and fishery products. A monitoring of *Salmonella* has been suggested as a measure of fish quality. Also, risk management decisions should take into account the whole food chain from primary production to consumption, and should be implemented in the context of appropriate food safety infrastructures, for instance regulatory enforcement, food product tracing and traceability systems. In the fish processing chain managing risks should be based on scientific knowledge of the microbiological hazards and the understanding of the primary production, processing and manufacturing technologies and handling during food preparation, storage and transport, retail and catering (Popovic et al., 2010). Their presence in fish and fishery product is therefore seen as a sign of poor standards of process hygiene and sanitation (Dalsgaard, 1998).

2. Description of *Salmonella*

Salmonella is a member of the Enterobacteriaceace, Gram negative, motile, with peritrichous flagella and nonsporeforming rods (the rods are typically 0.7-1.5 µm x 2.5 µm in size). *Salmonella* is a facultatively anaerobic (can grow with or without oxygen) catalase positive and oxidase negative bacteria. However, *Salmonella* is not included in the group of organisms referred to as coliforms (Huss & Gram, 2003; Adams & Moss, 2005; Erkmen, 2007; Lawley et al., 2008). These mesophilic organisms are distrubuted geographically all over the world, but principally occurring in the gastrointestinal tracts of mammals, reptiles, birds, and insects and environments polluted with human or animal excreta (Huss, 1994, Huss & Gram, 2003; Saeed & Naji 2007). Survival in water depends on many parameters such as biological (interaction with other bacteria) and physical factors (temperature). More than 2,500 different types of *Salmonella* exist, some of which cause illness in both animals and people. Some types cause illness in animals but not in people. The various forms of *Salmonella* that can infect people are referred to as serotypes, which are very closely related microorganisms that share certain structural features. Some serotypes are only present in certain parts of the world (Brands, 2006). For over 100 years *Salmonella* have been known to cause illness. The bacterium was first isolated from pigs suffering hog cholera by an American scientist, Dr. Daniel Elmer Salmon, in 1885 (Bremer et al., 2003).

3. Sources of *Salmonella* contamination in fish and fishery products

Aquatic environments are the major reservoirs of *Salmonella*. Therefore, fishery products have been recognized as a major carrier of food-borne pathogens (Kamat et al., 2005; Upadhyay et al., 2010).

Pathogenic bacteria associated with fish and fishery product can be categorised into three general groups: (1) bacteria (indigenous bacteria) that belong to the natural microflora of fish (*Clostridium botulinum*, pathogenic *Vibrio* spp., *Aeromonas hydrophila*); (2) enteric bacteria (non-indigenous bacteria) that are present due to fecal contamination (*Salmonella* spp., *Shigella* spp., pathogenic *Escherichia coli*, *Staphylococcus aureus*); and (3) bacterial contamination during processing, storage or preparation for consumption (*Bacillus cereus*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Clostridium perfringens*, *Salmonella* spp.) (Lyhs 2009).

Information from literature indicates that fresh fish, fish meal, oysters, farmed and imported frozen shrimp and froglegs can carry *Salmonella* sp., particularly if they are caught in areas contaminated with faecal pollution (prior to harvest and during harvest) or processed, packed, stored, distributed under unsanitary conditions and consumed raw or slightly cooked (Kumar et al., 2003; Kamat et al., 2005, Mol et al., 2010; Norhana et al., 2010).

There are some pathways of contamination of aquaculture systems with *Salmonella.*

Non-point water run-off

During rainfall events, increased run off of organic matter into ponds may occur and can contaminate the aquaculture system.

Animals (domestic animals, frogs, rodents, birds, insects, reptiles, etc.)

A variety of animal waste has been shown to be potential sources of *Salmonella*. Animal waste can be introduced directly through bird droppings or frogs living in ponds or indirectly through runoff.

Fertilization of ponds

In some aquaculture systems animal manures are used in ponds to stimulate the production of algae. The use of non-composted manures can lead to production systems being contaminated with *Salmonella*.

Contaminated feed

Improperly stored feed or feed prepared on a farm under poor hygienic conditions can be a source of *Salmonella*.

Contaminated source water

The water used in growout ponds, cages or tanks can be contaminated with *Salmonella* through wildlife runoff, untreated domestic sewage, discharge from animal farms, etc.

On farm primary processing

Aquaculture products can become contaminated with *Salmonella* through the use of unsanitary ice, water, containers, and poor hygienic handling practices (FAO, 2010).

For example, for shrimp processing industry the information from literature indicates that the principal sources of *Salmonella* contamination are culture ponds, coastal water used for handling and processing of seafood (Hariyadi et al., 2005; Shabarinath et al., 2007; Upadhyay et al., 2010). Similarly, Pal and Marshall (2009) reported that the potential source of *Salmonella* contamination in farm-raised catfish is likely due to poor water quality, farm runoff, fecal contamination from wild animals or livestock, feed processing under poor sanitary conditions or distribution, retail marketing, and handling/preparation practices.

Ray et al.,(1976) reported that the potential hazard in cooked fishery product is cross contamination of the cooked products with raw fishery product which might occur under commercial processing condition. Thus, good sanitation practices on the unloading docks and during transport to the processing facility are essential for preventing product contamination. The use of contaminated ice or uncleaned holding facilities may also contribute to the product contaminant load (Gecan et al., 1988). As a result, many factors including inadequate supplies of clean water, inadequate sanitary measures, lack of food hygiene and food safety measures have been responsible for increased incidence of foodborne salmonellosis (Shabarinath et al., 2007).

Deep-sea fish are generally *Salmonella* sp. free but susceptible to contamination post-catch. Water temperature has been

proposed as playing an important role in the long-term survival of *Salmonella* in the environment (FAO, 2010). In raw seafood products mainly from tropical climates, there is a high prevalence of *Salmonella* whereas low prevalence or absence can be common in temperate regions (Millard and Rocklif, 2004).

4. Occurrence in fish and fishery product

Salmonella has been isolated from fish and fishery product, though it is not psychrotrophic or indigenous to the aquatic environment (Mol et al., 2010). The relationship between fish and *Salmonella* has been described by several scientists; some believe that fish are possible carriers of *Salmonella* which are harbored in their intestines for relatively short periods of time and some believe that fish get actively infected by *Salmonella*. The organism was never recovered from the flesh of the fish, but was isolated from viscera and epithelium (Pullela, 1997). Most outbreaks of food poisoning associated with fish derive from the consumption of raw or insufficiently heat treated fish and cross-contamination during processing and about 12% of the foodborne outbreaks related to consumption of fish are caused by bacteria including *Salmonella* (Huss et al., 2000; Aberoumand, 2010). Similarly, The U.S. Food and Drug Administration's (FDA) data showed that *Salmonella* was the most common contaminant of fish and fishery products (Allshouse et al., 2004). Up to 10-15% of fish samples from India and Mexico were positive of *Salmonella* which has also been detected in several crustacean and molluscan products from India and Malaysia (Huss & Gram 2003). *Salmonella* contamination in fish and fishery products has also been reported from other countries like Thailand, Hong Kong, Spain and Turkey (Herrera et al., 2006; Kumar et al., 2009; Pamuk et al, 2011). The highest *Salmonella* incidence in fishery products was determined in Central Pacific and African countries while it was lower in Europe and including Russia, and North America (Heinitz et al. 2000). For example, Davies et al. (2001) reported the absence of *Salmonella* in fish from European Countries such as France, Great Britain, Greece and Portugal. However, Novotny et al., (2004), reported an outbreak of *Salmonella* blockley infections following smoked eel consumption in Germany. *Salmonella* paratyphi B infections were also reported associated with consumption of smoked halibut in Germany (Da Silva, 2002). Besides, consumption of dried anchovy was found to be the cause of *Salmonella* infection (Ling et al., 2002).

Table 1 shows the incidence of salmonellosis associated with all food vehicles, and with separately seafood, for the European Union in 2007 (FAO,2010).

Food vehicle	**Number of outbreaks**	**Number of *Salmonella* outbreaks**	**% of outbreaks associated with *Salmonella***
Fish and fishery products	130	3	2.3
Crustaceans, shellfish, molluscs, and products	75	2	2.7
All food vehicles	2025	590	29.1

Table 1. Fishery product associated outbreaks in the European Union, 2007 (Data from FAO,2010)

Salmonella has also been detected in US market oysters and in other US imported seafood from different countries (Heinitz et al. 2000; Ponce et al., 2008). For the 9-year period 1990–1999, the FDA in the United States examined imported and domestic fish and seafoods for *Salmonella*. Of the 11.312 imported samples, 7.2% were positive while only 1.3% of the 768 domestic samples were positive.

The most common serovar found in the world was *S. Weltvreden* (Heinitz et al. 2000; Jay et al., 2005). In seafood the commonest serotype encountered was S. Worthington followed by S. Weltevreden. The diversity of serovars associated with fish and fishery product was highest in Southeast Asia and next highest in South America (FAO, 2010). Most *Salmonella* contamination problems in fishery product associated with shrimp. Almost one-quarter of all detentions, and more than half of the violations for *Salmonella*, were for shrimp and prawns (farm raised and wild caught).

Salmonella Serotype	India/ SE Asia	Africa	Central America	Central pacific	Eastern Caribbean	Europe and Russia	Mexico	Middle East	North America/ Multiple	South America
S. Abaetetu			+							+
S. Aberdeen	+									
S. Agona	+						+			+
S. Ahepe		+								
S. Albany	+									
S. Anatum	+			+	+	+	+			+
S. Anfo	+									
S. Arizonae	+			+			+			+
S. Atakpam	+									
S. Augusten	+									
S. Baguida										+
S. Bareilly	+						+			
S. Biafra	+									
S. Blockley	+									
S. Bovis-mobificans	+			+						
S. Bradford	+									
S. Braender	+									
S. Brancast	+									
S. Bredeney										+
S. Brunei	+									
S. Bullbay										+
S. Cannstat							+			
S. Carrau			+							
S. Cerro	+									+
S. Derby	+			+						
S. Drypool	+									
S. Dublin	+									
S. Duesseldorf				+						
S. Emek	+									
S. Emek	+									
S. Enteritidis	+	+		+			+		+	+
S. Farmsen	+									
S. Gallinaru	+									
S. Georgia	+									
S. Gwaai					+					
S. Hadar	+			+			+	+		
S. Harmelen			+							
S. Havana	+				+					
S. Havana										

Salmonella Serotype	India/ SE Asia	Africa	Central America	Central pacific	Eastern Caribbean	Europe and Russia	Mexico	Middle East	North America/ Multiple	South America
S. Heidelber	+			+						+
S. Hilversum				+						
S. Houten			+	+						+
S. Houten	+									
S. Hull		+								
S. Hvittingfoss	+									
S. Idikan	+									
S. Infantis	+		+		+					
S. Irumu	+									
S. Isangi	+									
S. Javiana	+			+						+
S. Kentucky	+			+			+			+
S. Kirkee	+									
S. Kottbus	+									
S. Krefeld	+									
S. Kumasi	+									
S. Lanka	+						+			
S. Lansing	+									
S. Lexington	+									
S. Liandoff							+			
S. Lindenburg	+									
S. Litchfield										+
S. Liverpool	+									
S. London	+			+						
S. Manila				+						
S. Marina										+
S. Mbandaka	+		+							
S. Meleagridis	+						+			
S. Mendoza										+
S. Mgutani	+									
S. Miami		+								
S. Michigan							+			
S. Minnesota	+						+			
S. Montevideo	+									
S. Morehead	+									
S. Mosselbay										+
S. Muenchen	+						+			
S. Muenster	+				+					
S. Nairobi		+								+

Salmonella Serotype	India/ SE Asia	Africa	Central America	Central pacific	Eastern Caribbean	Europe and Russia	Mexico	Middle East	North America/ Multiple	South America
S. Nchanga	+									
S. Newbrunswick							+			
S. Newington										+
S. Newport	+		+	+					+	+
S. Ohio	+						+			
S. Onireke		+								
S. Oranienburg	+				+		+			+
S. Orientalis				+						
S. Oslo	+		+							
S. Othmarschen	+									
S. Panama										+
S. Paratyphi B	+			+						
S. Paratyphi B Java	+									
S. Parera		+								
S. Phoneix										+
S. Pomana			+				+			
S. Poona	+		+				+			
S. Potsdam	+									
S. Pullorum				+						
S. Reading	+									
S. Redba		+								
S. Reinikendorf	+									
S. Riggil	+									
S. Rissen	+									
S. Rubislaw		+	+				+			
S. Saintpaul	+			+			+	+	+	+
S. Saka		+								+
S. Sandiego	+									
S. Saphra							+			
S. Sarajane	+									
S. Schleisshein	+									
S. Schwarzengrun										
S. Senftenberg	+		+		+		+	+		
S. Singapore	+									
S. Srinagar	+									
S. Stanley	+			+						
S. Takoradi	+									

Salmonella Serotype	India/ SE Asia	Africa	Central America	Central pacific	Eastern Caribbean	Europe and Russia	Mexico	Middle East	North America/ Multiple	South America
S. Tananarive	+									
S. Telelkebir		+								
S. Tennessee	+						+			
S. Thompson	+			+			+		+	
S. Tornow				+						+
S. Typhi	+									
S. Typhimurium	+		+		+		+		+	+
S. Uganda					+					
S. Urbana	+									
S. Virchow	+			+					+	
S. Wandsworth	+									
S. Washington	+									
S. Weltevreden	+		+	+		+	+			+
S. Weston	+									
S. Worthington	+									

Table 2. *Salmonella* serotype reported in fish and fishery products (Data from FAO, 2010)

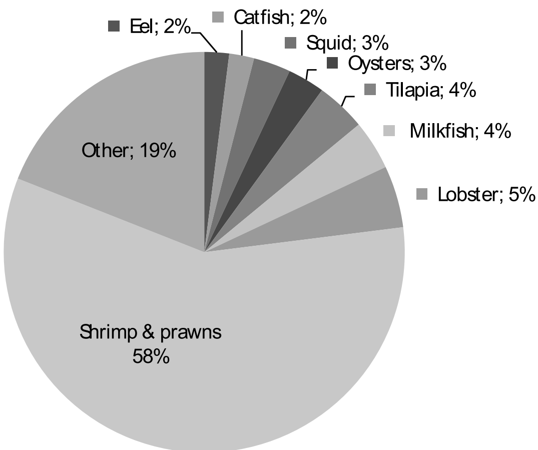

Fig. 1. Share of FDA violations for *Salmonella*, by fishery product, 2001 (data from Allshouse et al., 2004).

5. Survival and growth parameters

Salmonella sp. can multiply and survive in the estuarine environments and tropical freshwater environments for weeks although open marine waters are free from *Salmonella* (Huss,1994; Huss & Gram 2003). *Salmonella* prefers to grow at 37°C. Compared to other Gram-negative bacteria, *Salmonella* are relatively resistant to various environmental factors. They grow at temperatures between 5°C and 47°C. There are reports that they survive for longer than *E. coli* in sea and freshwater environments (Huss, 1994; Sugumar & Mariappan, 2003; Marriot & Gravani, 2006). *Salmonella* have been also reported to be able to grow within the temperature range of 2-54°C, although growth below 7°C has largely been observed only in microbiological culture media and growth above 48°C is confined to mutants or tempered strains (Bremer et al. 2003). A few *Salmonella* serotypes can grow over a pH range of 3.6–9.6, which is mildly basic to strongly acidic. Optimum growth occurs at a pH of 6.5–7.5, which is close to neutral. Other factors such as temperature, the type of acid present and the presence of antimicrobials can effect the minimum pH for growth (Brands, 2006; Marriot & Gravani, 2006; Lawley et al., 2008). It requires a minimum Aw of 0.94 (and possibly 0.93) with a maximum salt content of 4.0% to 5.0% (Huss, 1994; Lawley et al., 2008). A study by Basti et al., (2006), for example, showed complete elimination of *Salmonella* on heavy salted fish and heavy salted cold smoked fish due to the high concentration levels of NaCl (>7%). Limiting conditions were summarized for *Salmonella* in Table 3.

Pathogen	min. Aw (using salt)	min. pH	max. pH	max.% water phase salt	min. temp	max. temp	Oxygen requirement
Salmonella spp.	0.94	3.7	9.5	5	5 °C	47 °C	facultative anaerobe

Table 3. Limiting Conditions for *Salmonella* Growth

6. Control of *Salmonella* in fish and fishery products

Since most of fish products, with the exception of coldsmoked fish, sushi, and a few specialty products such as spiced, salted, or pickled fish, are expected to be cooked prior to consumption, the presence of microbiological pathogens should not present a human health hazard (Flick, 2008).

The aquaculture farm is the first link in the food safety continuum and controls must be in place and implemented throughout the food safety chain. The experts agreed that good hygienic practices during aquaculture production and biosecurity measures can minimize but not eliminate *Salmonella* in products of aquaculture.

Some important control measures to minimize the risk of *Salmonella* contamination of aquaculture products according to FAO (2011)

Farm location

- Farms should be secured from the entry of wild and domestic animals that may lead to the contamination of aquaculture products with *Salmonella*.

Farm layout, equipment and design

- Farm design and layout should be such that prevents cross contamination

- Equipment such as cages, nets and containers should be designed and constructed to allow for adequate cleaning and disinfection
- Septic tanks, toilet facilities and bathrooms/showers should be constructed and placed so drainage does not pose a risk of contamination of farm facilities.

Source water

- Farm source water should be free from sewage contamination and suitable for aquaculture production
- Farms should have settling ponds or waste water treatment in place to condition the output water prior to discharge

Ice and Water Supply

- Potable or clean water is available and used in sufficient amount for harvest, handling and cleaning operations
- Ice should be manufactured using potable water and produced under sanitary conditions
- Ice should be handled and stored under good sanitary conditions which precludes the risk for contamination.

Harvesting

Harvesting equipment and utensils easy to clean and disinfect and kept in clean condition.

- Harvesting is planned in advance to avoid time/temperature abuse.
- Aquaculture products should be hygienically handled.
- Records on harvesting are maintained for traceability.

On farm post-harvest handling

- Utensils and equipment for handling and holding of aquaculture products is maintained in a clean condition.
- Aquaculture products are cooled down quickly and maintained at temperatures approaching that of melting ice.
- Operations such as sorting, weighing, washing, drainage, etc., are carried out quickly and hygienically.
- All additives and chemicals (disinfectants, cleaning agents, etc) used in post-harvest aquaculture products should be approved by the national competent authority.

Transport of aquaculture products from farm

- Transport is carried out in easy to clean and clean facilities (boxes, containers, etc.).
- Conditions of transport should not allow contamination from surroundings (e.g. dust, soil, water, oil, chemicals, etc.).
- Aquaculture products are transported in containers with ice or with, in sufficient amounts to ensure temperature around 0ºC (approaching that of melting ice) in all products and during the whole period of transport.

Employee health

- Staff should be medically fit to work and should be screened regularly to determine carriers of *Salmonella*.

On the other hand, a number of studies have been carried out to develop methods to control contamination of proceed fishery products. They are sub-divided into physical or chemical approaches (Norhana et al., 2010).

7. Physical approaches

7.1 Cooking

Application of heat is one of the simplest and most effective methods of eliminating pathogens from food. Heat application of 90°C for 1.5 min. in the center for mollusc and 99–100°C for 3–4 min. for shellfish are accepted as safe processes before consumption. These temperatures are sufficient for the destruction of vegetative forms of the pathogens (Olgunoglu, 2010). Ray et al. (1976) reported that the processing of blue crabs involving steam cooking with pressure of approximately 15 psi (121°C) for 10 min. is sufficent to kill pathogens on the raw crab. Vegetative, unstressed *Salmonella* cells are heat-sensitive and are easily destroyed at pasteurisation (hot-smoking) temperatures. D-values (Decimal reduction time) at 60°C are typically 1-3 minutes (Huss & Gram 2003). Time/Temperature Guidance for Controlling *Salmonella* growth in Fishery Products were given Table 4.

Potentially Hazardous	Product Temperature	Maximum Cumulative Exposure Time
Growth of *Salmonella* species	5.2-10˚C 11-21˚C above 21˚C	2 days 5 hours 2 hours

Table 4. Time/Temperature Guidance for Controlling *Salmonella* Growth inFih and Fishery Products (FDA, 2011)

7.2 Refrigeration

Refrigeration and freezing are well-known techniques for extending the shelf-life of food products. These processes lower the temperature to levels at which bacterial metabolic processes are stopped and the rates of chemical and biochemical reactions reduced (Norhana et al., 2010). Although most *Salmonella* serotypes are unable to grow at refrigeration temperatures, the organismis can be prevented holding chilled fishery products below 4.4°C (Ward &Hart, 1997). Worldwide, the most common cause of foodborne salmonellosis is *Salmonella typhimurium*. The minimum growth temperature reported for this species is 6.2°C (A study by Ingham et al., (1990), indicate that the temperature preventing growth of S. typhimurium in picked crab meat is at or below 7°C). Thus, proper refrigeration will prevent growth of S. Typhimurium. However, maintenance of optimal refrigeration temperatures often cannot be guaranteed at all times prior to food consumption (Ingham et al., 1990). Thus, good sanitation after refrigeration process of fishery products such as cooked crabs or cooked shrimp are very important in maintainning product quality(Ray et al., 1976).

7.3 Irradiation

The irradiation of fishery products is a physical treatment involving direct exposure to electron or electromagnetic rays, for their long time preservation and improvement of quality and safety (Oraei et al., 2011; Özden & Erkan, 2010). Irradiation of food has been legally allowed in many countries and the WHO has sanctioned radiation of up to 7.0 kilo Gray (kGy) as safe. This process is one of the most effective methods for decontaminating both the surface and deep muscle of fresh meat. There is substantial literature on the effects of irradiation in reducing *Salmonella* on some fishery product such as shrimp (Norhana et al., 2010). The alteration in pathogen population as a result of irradiation depends on the dose of irradiation, storage temperature, packaging conditions and fish species (Özden et al., 2007). For example a study, showed complete elimination of *Salmonella* on frozen shrimp when irradiated at 4.0 kGy. Similarly it is also reported that doses of 4.0–5.0 kGy were required to reduce the numbers of *S. typhimurium* on shrimp by 6.0 log cycles. According to Oraei et al., (2011), low-dose gamma irradiation (especially 3 kGy) can be applied for microbial control and the safety of rainbow trout and shelf life extension in frozen state. Gamma irradiation at 3 kGy was more effective than irradiation at 1 and 5 kGy in eliminating microorganisms of rainbow trout fillets. The irridation doses are also reported in the range 1.5–2.0 kGy effectively control all pathogenic bacteria tested in shellfish except *Salmonella* spp., particularly, *S. enteritidis*, which requires 3.0 kGy (IAEA,2001). Similarly to achieve safety levels against *Salmonella* spp., particularly *S. enteritidis*, in raw oysters, a dose of 3.0 kGy is recommended by Gelli (2001). As a results although irradiation appears to be effective in eliminating pathogens in fishery product, there is an unsubstantiated view amongst the public that food irradiation is unsafe and undesirable. There is also evidence some that irradiation may reduce the nutritional value of some foods by the destruction of aromatic amino acids and producing rancidity and off-odours (Norhana et al., 2010).

8. Modified atmosphere packaging (MAP)

Modifed atmosphere packaging (MAP) has been widely used for extending the shelf life of a wide variety of food, including fish and fish products since 1980. Packages are injected with carbon dioxide, nitrogen, and very small (0.4 percent) amounts of carbon monoxide. The effciency of MAP in eliminating pathogens from fish depends on the gas mixture in MAP and, most importantly, the storage temperature (Redman, 2007; Hudecová et al., 2010). There is limited information on the effect of MAP with elevated O_2 level on *Salmonella* in the literature. A study by Hudecová et al., (2010), for example, showed a signifcant decrease in the microbial growth rate on fresh chilled common carp (Cyprinus carpio) during storage at +4 ± 0.5 °C in two different MAP (70% N_2/30% CO_2 and 80% O_2/20% CO_2) for 10 days when compared to air packaging and no *Salmonella* was reported in these conditions. Ingham et al., (1990) reported that modified atmosphere storage using 50% CO_2/10% O_2 dose effectively reduce the growth rate of *S. typhimurium*, but it cannot, in the absence of proper refrigeration, be relied upon to prevent salmonellosis.

9. High-pressure processing (HPP) and superheated steam drying (SSD)

High-pressure processing is an emerging non-thermal process that can be used to destroy pathogenic microorganisms in seafood without greatly affecting the quality of the product. In addition to improving the safety of shrimp, HPP has also been demonstrated to extend shrimp shelf-life. Shrimp are generally spoiled by Gram-negative bacteria, which tend to be relatively pressure sensitive due to their cell wall structure and HPP may therefore prove to be a valuable processing technology for shrimp. Although research has demonstrated the benefit of using HPP on shrimp and shrimp products, limited studies have been carried out specifically to eliminate or reduce *Salmonella* in fishery product using this technology.

Superheated steam drying (SSD) is a promising drying technology to a variety of industries. Superheated steam is steam heated to a temperature higher than the boiling point corresponding to its pressure (Norhana et al., 2010).

10. Chemical approaches

10.1 The use of antimicrobial agents

Chlorine is the decontaminating agent most widely used to kill pathogenic microorganisms in the seafood industry. It is used to disinfect water used in the process (such as thawing frozen products), washing raw materials and in making ice for chilling fishery products. Commonly used chlorine compounds are liquid chlorine solution (HOCl) and hypochlorite (OCl^-). More recently chlorine dioxide (ClO_2) and electrolyzed oxidizing (EO) water have also been used for this purpose. Specifically, ClO_2 has been recognized as a bactericidal, viricidal and fungicidal agent and is widely used in Europe and US as an alternative to chlorine and hypochlorite. In addition, EO water has also been shown to possess strong bactericidal activity against various foodborne pathogens.

Both gaseous and dissolved forms of ozone are approved to be used as antimicrobial agents by the food industry, including the seafood industry. There are investigations on the effect of 2% ozonated saline (5.2 mg ozone/L, 5°C) on the inactivation of nine bacterial strains (including *S. typhimurium*) in shrimp meat. Findings showed that *S. typhimurium* was the most resistant of the species tested, with only 0.1 log cycle reductions (Norhana et al., 2010).

Lactate is considered to be an effective additional hurdle against the growth of contamination flora and pathogens such as *Salmonella* and it is used in the further processed fish industry (fish cakes, smoked salmon, injected fillets, marinated fish). Studies on the specific action of lactates indicate they stimulate mechanisms that interfere with the metabolism of the bacteria, such as intercellular acidification and interfere with proton transfer across the cell membrane and feedback inhibition. Lactate also lowers water activity. Since lactate does not kill bacteria, it cannot be used to mask poor sanitation practices (Da Silva 2002).

11. International commision on microbiological specification for food (ICMSF) recommended microbial limits

Product	n[1]	c[2]	Bacteria/gram or cm^2	
			m[3]	M[4]
Fresh and frozen fish and cold-smoked fish	5	0	0	-
Frozen raw crustaceans	5	0	0	-
Frozen cooked crustaceans	10	0	0	-
Fresh and frozen bivalve molluscs	20	0	0	-

[1]Number of representative sample units.
[2]Maximum number of acceptable sample units with bacterial counts between m and M.
[3]Maximum recommended bacterial counts for good quality products.
[4]Maximum recommended bacterial counts for marginally acceptable quality products. Plate counts below "m" are considered good quality. Plate counts between "m" and "M" are considered marginally acceptable quality, but can be accepted if the number of samples does not exceed "c." Plate counts at or above "M" are considered unacceptable quality (SeafoodNIC; http://seafood.ucdavis.edu/haccp/compendium/chapt17.htm)

Table 5. Recommended microbiological limits for *Salmonella* spp. in fish and fishery products

12. Conclusions

Significant numbers of detections of *Salmonella* in fish and fishery products indicate that current strategies for *Salmonella* control in the aquaculture production and processing sectors are not adequate. While some marine fish caught offshore and handled hygienically and at low temperature according to the Codex Code of Practice for fish and fishery products (CAC/RCP/52-2003) may be suitable for raw consumption, it would be advisable to consume products of aquaculture only after cooking. The *Salmonella* problem should be resolved by the use of good manufacturing procedures and the strict application of sanitary practices. On the other hand, Hazard analysis and critical control point (HACCP) systems should be implemented increasingly by private industry for seafood, sometimes voluntarily and sometimes as mandated by Federal governments. These must be rigidly enforced throughout the processing line and require the full understanding and cooperation of plant management and every employee. Investment in new technologies and equipment will also improve the seafood safety.

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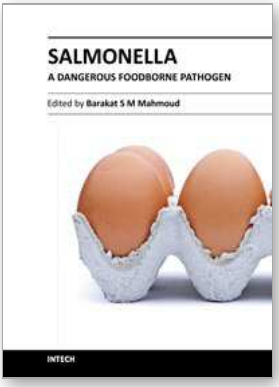

Salmonella - A Dangerous Foodborne Pathogen

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More than 2,500 serotypes of Salmonella exist. However, only some of these serotypes have been frequently associated with food-borne illnesses. Salmonella is the second most dominant bacterial cause of food-borne gastroenteritis worldwide. Often, most people who suffer from Salmonella infections have temporary gastroenteritis, which usually does not require treatment. However, when infection becomes invasive, antimicrobial treatment is mandatory. Symptoms generally occur 8 to 72 hours after ingestion of the pathogen and can last 3 to 5 days. Children, the elderly, and immunocompromised individuals are the most susceptible to salmonellosis infections. The annual economic cost due to food-borne Salmonella infections in the United States alone is estimated at $2.4 billion, with an estimated 1.4 million cases of salmonellosis and more than 500 deaths annually. This book contains nineteen chapters which cover a range of different topics, such as the role of foods in Salmonella infections, food-borne outbreaks caused by Salmonella, biofilm formation, antimicrobial drug resistance of Salmonella isolates, methods for controlling Salmonella in food, and Salmonella isolation and identification methods.

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