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Review

Foods, fish and salmonellosis

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Foodborne diseases are those caused by the consumption of water and food contaminated by different causal agents such as viruses, bacteria, parasites, toxins, among others, being considered an important public health problem global due to its incidence and mortality and for several years for the isolation of microorganisms that cause these diseases resistant to antimicrobials. *Salmonella* species is considered a food pathogen frequently responsible for infectious outbreaks through the consumption of contaminated food, also presenting resistance to different antimicrobials. Fishery products are recognized as an important source of food, nutrition, income and a source of livelihood for a large part of the world's population. However, fish is also considered to be a vehicle that transmits different pathogens (*Salmonella* spp., *Shigella* species, *Escherichia coli, Listeria monocytogenes* among others) mainly due to inadequate hygiene practices along the food chain. The purpose of this article is to show in a general way a perspective of foodborne diseases, specifically those caused by bacteria of the genus *Salmonella* spp., through fish such as tilapia, the control and prevention measures of these pathogens in food, the phenomenon of resistance to antimicrobials by these bacteria isolated in food and fish around the world that exacerbates the problem in food safety and public health.

Key words: *Salmonella*, food, fish, processing, antimicrobial.

INTRODUCTION

Foodborne diseases (FD) are considered an important public health issue at the international level due to their incidence and mortality rates as well as the negative economic-productive repercussions associated with health services and the implementation and monitoring of health policies and food safety (Zamudio et al., 2011; Olea et al., 2012; Puig et al., 2013). These diseases are generated due to the consumption of food or water contaminated by physical, chemical or microbiological agents during any phase of the food chain (primary production, processing, handling, conservation, transport, distribution or commercialization) distinguishing themselves in infections or food poisoning (De Fuente and Barboza; 2010; Zamudio et al., 2011; Badui, 2015; Jorquera et al., 2015).

Foodborne diseases are characterized by different

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symptoms that generally include nausea, vomiting, diarrhea, abdominal pain, and fever; in some cases, severe complications may occur, such as sepsis, meningitis, Reiter syndrome, Guillan Barré syndrome or death, with population groups such as children, pregnant women and the elderly being more severely affected (Soto et al., 2016). According to estimates of the World Health Organization (WHO) annually around the world, 1500 million cases of diarrhea are generated, passing away three million children under five years of age is a high proportion due to the consumption of food and water contaminated (López et al., 2013). Only in countries like the United States of America (USA), it is estimated that around 76 million people suffer from a foodborne illness, of which 325,000 require hospital care and 5,000 dies every year and involving high health costs (Olea et al., 2012).

Approximately, more 250 disease-causing agents derivate by consumption of food has been identified, which includes bacteria, viruses, fungi, parasites, prions, toxins and metals (Olea et al., 2012). Most infections are generated by bacteria, viruses, and parasites; being between these the bacterial the mostly reported among which are*: Salmonella, Vibrio, Staphylococcus aureus, Bacillus cereus, Clostridium perfringens, Escherichia coli, Listeria monocytogenes, Campylobacter,* and *Shigella* species among others (Puig et al., 2013; Jorquera et al., 2015; Soto et al., 2016).

Some of the factors that have caused a higher rate of food contamination and incidence of these diseases are market globalization, new manufacturing technologies and eating habits (Olea et al., 2012; Jorquera et al., 2015). The incidence of these diseases is a direct indicator of the hygienic-sanitary quality of food, demonstrating that the contamination of these can occur at any stage of the food chain either in the processing or use of contaminated raw materials (Flores and Herrera, 2005).

In the analysis of foodborne diseases and specifically related to fish and its relationship with biological agents contaminating foods such as *Salmonella* spp., Alerte et al. (2012) reported that in the Metropolitan Region of Chile between January 2005 and June 2010, there were 2806 outbreaks of which 2472 were investigated finding that 15.1% of the outbreaks are related to food such as fish, being *Salmonella* spp., the causal agent is 20.9% of the total outbreaks, also discovering that the main causes of the loss of food safety was the commercial and domestic manipulation, raw material, inadequate storage and processing.

On the other hand in Europe, Espinosa et al. (2014) through the data issued by the national network of epidemiological surveillance (RENAVE) of Spain in the period of the year 2008 to 2011 reported a total of 30219 cases of which 1763 were hospitalizations and 24 deaths of which *Salmonella* spp. was involved in 33.9% of the cases and the food involved was fish and products in 6.5% and among the contributing factors to such diseases were mainly the poor hygiene practices in handling, processing, storage, etc.

The purpose of this document is to show a general perspective of foodborne diseases, especially those caused by bacteria of the genus *Salmonella* spp., through fish such as tilapia, as well as the control and prevention measures of these pathogens in food. In addition, an outline of resistance to antimicrobials by *Salmonella* spp., in foods and fish is presented, which exacerbates the problem of loss of food safety and public health.

THE GENUS *SALMONELLA* SPP.

Bacteria of the genus *Salmonella* spp., belong to the family *Enterobacteriaceae*, are bacillus-shaped, Gram negative, non-sporulated, mobile, catalase positive, oxidase negative, aerobic and facultative anaerobes, grow in a temperature range from 5 to 47°C, with an optimum temperature of 35 to 37°C, the pH of growth is between 4 and 9 with an optimum between 6.5 and 7.5, and an activity water (Aw) of 0.99 to 0.94; two species are currently recognized: *Salmonella enterica* and *Salmonella bongori*, among which there are 2500 serotypes, classified according to flagellar antigen "H", somatic "O" and virulence "Vi". *S. enterica* is divided into six subspecies such as: *enterica, salamae, arizonae, diarizonae, houtenae* and *indica*, where *S. enterica*, subspecies *enterica*, presents 99% of serotypes isolated and related to infections in animals and humans (González et al., 2014; Soto et al., 2016; Cortes-Sánchez et al., 2017). The main reservoir of *Salmonella* spp. is the gastrointestinal tract of mammals, reptiles, fish, birds, and insects (Nwiyi and Onyeabor, 2012; Juno et al., 2013; González et al., 2014; Bibi et al., 2015).

The genus *Salmonella* spp., is of great importance in aspects of public health worldwide due to its incidence, virulence, adaptability and resistance to antimicrobials, causing diseases such as salmonellosis through the consumption of contaminated food and water such as meat, fish, vegetables, etc., and the most vulnerable population groups are children, the elderly, pregnant women and weakened immune system (Rivera et al., 2012; Nwiyi and Onyeabor, 2012; Junod, 2013; Soto et al., 2016; Cortes-Sánchez et al., 2017; Sheyin and Solomon, 2017). Once the salmonellosis is contracted, the symptoms manifest between 6 and 72 h after the ingestion of contaminated food, lasting between 2 and 7 days (WHO, 2018c). Annually, an estimated incidence of 1.3 billion cases of salmonellosis is estimated worldwide, with 3.0 million deaths and its common symptoms being vomiting, abdominal cramps, fever, headache, enterocolitis, diarrhea, blood in stools in severe cases can cause sepsis, endotoxemia, disseminated intravascular coagulation, multiple organ failure, and death (Rivera et al., 2012; Bibi et al., 2015).

FISH AS FOOD AND HEALTH

Fish is considered a globally important food, as it represents a source of nutrition, income, and livelihoods for hundreds of millions of people. In 2014, the world production of fish by capture and aquaculture was 167.2 million tons, of which 146.3 million were for human consumption (FAO, 2016). For the aquaculture sector, global trade in these products has increased considerably in recent decades and the expansion of aquaculture production, particularly in Asia, has the potential to satisfy a considerable part of the growing global demand for fish and fishery products; according to data from the Food and Agriculture Organization of the United Nations (FAO), aquaculture contributes around 50% of the world demand for fish and fishery products, with approximately 90% of aquaculture products coming from the Asian continent (Elhadi, 2014).

Fish is considered a basic nutritious food that is part of a healthy diet due to its composition as a source of water (66-81%), high-quality protein and digestibility due to being a source of essential amino acids (16-21%), carbohydrates (<0.5%), fat-soluble and water-soluble vitamins, minerals (1.2-1.5%) mainly calcium, potassium and phosphorus and lipids (0.2-25%) that include polyunsaturated fatty acids omega-3 such as: eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that provide benefits to cardiovascular and nervous system with hypo-triglyceridemic, hypo cholemic, antithrombotic, anti-inflammatory, anti-arrhythmic effects, among others. It should be noted that the chemical and nutritional composition of fish varies considerably between different species and also between individuals of the same species, according to age, sex, diet, environment and season (FAO, 1998; Bakr et al., 2011; De Oliveira and Amancio, 2012; Valenzuela et al., 2014, 2016; FAO, 2016; Sheyin and Solomon, 2017).

However, these same nutritional and chemical composition qualities mentioned earlier convert fish from the capture or culture through aquaculture into a highly perishable food product susceptible to deterioration, as well as to contamination of chemical origin (metals, pesticides, antibiotics) or biological (biotoxins, parasites, viruses and bacteria) that label it as a food of considerable risk to consumer health (Ferre, 2001; Martínez et al., 2008; Uresti et al., 2008; Chalen et al., 2010; Romero and Negrete, 2011; Martinez et al., 2012; Quintero et al., 2012; Ortega, 2014; Sheyin and Solomon, 2017; FAO, 2018).

FISH AS A SOURCE OF FOOD: THE CASE OF TILAPIA

It is generically called tilapia a group of teleost fishes belonging to the Cichlidae family originating from the African continent. The family includes the genera *Tilapia* and *Oreochromis*, which have gained relevance around the world in recent years at the level of cultivation and trade as a source of food for humans. Species of the genus *Oreochromis* species such as *Oreochromis niloticus*, called "Nile tilapia", *Oreochromis aureus*, "blue tilapia" and *Oreochromis* spp. or "red tilapia" are the most accepted in cultivation, because they have a period of short growth, easy handling (sowing, harvesting, transfers, etc.), tolerance to extreme conditions (low oxygen concentrations, high planting densities), high ammonium levels, low and high pH values), adaptability in food habits and good production parameters (feed conversion, weight gain, survival) (Wicki and Gromenida, 1998; Vega et al., 2009; Garcia et al., 2012).

Tilapia is considered a fish of good appearance, quick acceptance and nutritional value by be source of proteins with a content of 23.34 g/100 g, ashes of 1.94 g/100 g, water 72.36 g/100 g and total lipids of 2.26/100 g, which has a proportion of omega-3 fatty acids of 33 g/100 g of lipids and omega-6 of 47.7g/100 g of lipids which has been reported to be beneficial effects for consumer health and that make it part of a balanced diet and healthy (Izquierdo et al., 2000).

Tilapia comprising its seven species constitutes the second most important group of farmed fish, only behind carp species; this has spread more among all the farmed fish (Aquaculture). Worldwide, Asian countries such as China, the Philippines, Thailand, Indonesia, Taiwan, India, Malaysia followed by countries of the American continent such as Brazil, Honduras, Costa Rica, Ecuador, and United States of America, are listed as the main producers of tilapia (*O. niloticus*) (FAO, 2018a).

In Mexico, tilapia farming and fishing due to its volume is positioned in the fifth place of the fishing production in Mexico and its commercial value is positioned in the third place. The average annual growth rate of production in the last 10 years is 3.28% where aquaculture through extensive, semi-intensive and intensive systems (according to the fish culture density, food supply and cultivation technification) performs the main contribution of this product; cultivating eight types of tilapia, mainly: herbivorous tilapia, Nile tilapia, Stirling tilapia, white tilapia, Mozambique tilapia, orange tilapia, tilapia mojarra and Florida red tilapia (SAGARPA, 2013, 2016) being the states of the Mexican Republic as Jalisco, Chiapas, Veracruz and Michoacán the largest producers (SAGARPA, 2013).

DETERIORATION AND CONTAMINATION OF FISH AND TILAPIA

The deterioration of the fish starts from the death of the animal and is considered as all those stages that involve internal and external changes through which the fish passes since die until it reaches a decomposition or putrefaction degree, which results in a product not suitable for consumption (Avdalov, 2009; Gentile, 2010).

The most notorious change is the attack of rigor mortis where immediately after death, the muscle of the fish is relaxed, flexible and elastic texture commonly maintained for few hours and then the muscle becomes hard and rigid; the whole body then becomes inflexible so the fish is in rigor mortis; this condition is maintained for one or more days, subsequently the muscle relaxes again and regains flexibility, but not the elasticity prior to rigor. The ratio between the beginning and the resolution of the rigor varies according to the species and is affected by the temperature, handling, size and physical conditions of the fish; for example, *Tilapia mossambica* in a state of non-exhaustion prior to its death of 2 to 9 h, which is the beginning of rigor mortis after death with a duration of 26.5 h at a temperature of 0 to 2°C (FAO, 1998). In general, within the activities that the fish experience in the deterioration are: autolysis (self-digestion, endogenous enzymes), lipid oxidation and microbiological activity; changes in fish during spoilage can be perceptible at the sensory level and through chemical, physical and microbiological methods (FAO, 1998; Avdalov, 2009; Gentile, 2010).

The speed with which the fish deteriorates is related to the initial microbial load and the temperature at which it is handled and preserved, the higher the maintenance temperatures and the microbial count, the faster the deterioration is generated (Gentile, 2010; Sheyin and Solomon, 2017). A characteristic of fish such as tilapia is that they have a large number of nitrogen compounds which makes them even more prone to deterioration, which is why they are commonly kept alive even before consumption (Sheyin and Solomon, 2017).

The fish's microbiota is related to the environmental conditions and food availability of their habitat. Water from rivers and lakes has a complex population that includes aquatic species, as well as terrestrial, animal and plant sources. On the other hand, anthropogenic activities have had a detrimental effect on both coastal and continental waters being contaminated with wastewater, giving rise to the risk that enteric microorganisms may be present and contaminate aquatic sources and therefore fish products. This does not further exempt that, depending on the type of fishing, aquaculture and hygiene practices during inappropriate handling or processing to which the different products are subjected, they may contribute to contamination with harmful biological or chemical agents, generating a risk to the health of the consumer (Avdalov, 2009; Gentile; 2010; Quintero et al., 2012; Sheyin and Solomon, 2017).

Pathogenic microorganisms in fresh fishery products may be related to fecal contamination of the water from where they were captured or cultivated. Fish function as a passive carrier of *Salmonella* spp. which can excrete it without apparent symptoms and clinical disease in fish species such as tilapia (*O. niloticus*) where the isolation of *Salmonella* spp. has been reported, mainly in organs such as intestines, skin, and galls (Bibi et al., 2015). Studies have also been carried out on the prevalence of this pathogen around the world in fish such as tilapia, which is extracted from various aquatic sources, showing biological contamination such as *Salmonella* spp*.* which is reflected in the possible risk of acquiring diseases when extracted and consume these products; such is the case of Nile tilapia (*O. niloticus*) from Lake Victoria Beaches in Western Kenya where contamination with enteric bacteria such as *S. Typhimurium* was reported, followed by *typhi* and *enteritidis*, estimating that the source of contamination is of human or animal origin (Awuor et al., 2011).

Likewise, in microbiological studies of fresh tilapia sold to the general public in three markets of Nigeria, it was reported that samples of fresh tilapia in a period of the year 2010 to 2012 presented in body, gills, and guts the presence of *Salmonella* spp. suggesting a source of cross-contamination in the preparation of these products for consumption as well as focusing and promoting further studies of pathogen transmission along the food chain (Nwiyi and Onyeabor, 2012). On the other hand, Ismail et al. (2016) conducted a study among associations on water quality and the presence of bacteria in tilapia culture in floating cages in lakes and rivers in Peninsular Malaysia (Pedu Lake in Kedah and Kenyir Lake in Terengganu and Terengganu River) over a period of 24 months indicating the presence of various bacteria including those of a pathogenic nature for both humans (*Salmonella* spp.) and fish (*Vibrio* spp*., Aeromonas hydrophila,* and *Streptococcus* spp.) where water quality is an important aspect of aquaculture. Concluding that non-optimal physicochemical parameters of water (dissolved oxygen, pH, salinity, ammonia, temperature, etc.) and poor management practices (overfeeding, inadequate nutrition, overcrowding, etc.) can cause stress in intensively farmed fish and make them susceptible to outbreaks of diseases with harmful effects on water quality, so it is necessary to understand the microbiological-fish-environment association for an adequate and timely management of food production and safety through aquaculture.

CONTROL AND PREVENTION OF FOODBORNE DISEASES

Food safety is considered as a guarantee that food will not cause harm to the consumer when prepared and consumed according to the intended use, and is considered one of the four basic groups of characteristics that, in combination with nutritional, organoleptic and commercial, make up the total quality of food (De la Fuente and Barboza, 2010; Jorquera et al., 2015).

Fishery products are recognized as an important transmitter of microorganisms thus compromising their safety as food. The pathogenic microorganisms related to fish and products can be grouped into three general groups: (a) Autochthonous bacteria that belong to the natural microflora of fish (*Clostridium botulinum, Vibrio* spp*.,* and *A. hydrophila*); (b) Enteric bacteria whose presence is due to fecal contamination (*Salmonella* spp., *Shigella* spp., *Escherichia coli, Staphylococcus aureus*); and (c) Bacterial contamination during processing, storage or preparation for consumption (*Bacillus cereus, L. monocytogenes, Staphylococcus aureus, C. perfringens, Salmonella* spp*.*) (Elhadi, 2014).

The knowledge of the microbiota of fishery products through the microbial load of organs such as the skin, gills, and intestine allows to determine the microorganisms that are indicators of hygienic-sanitary quality and which ones can be activated during deterioration; the relevance of these organs lies in that they are in direct contact with the muscle and constitute the origin of the bacterial invasion, so if the number of bacteria increases in the said organs, proportionally it will increase in the muscle (Fuentes et al., 2011). The presence of various pathogenic bacteria is important for fish processing where process design and handling are involved in order to eliminate or inhibit them (Sheyin and Solomon, 2017).

The actions that have been developed around the world in order to generate safe food, avoiding and controlling the presence of bacterial pathogenic as *Salmonella* spp., including fish and products is through the application of different hygiene procedures along the food chain such as good agricultural practices, good livestock practices, good aquaculture and fishing practices and good manufacturing practices as well as the implementation of systems for Hazard Analysis and Critical Control Point (HACCP) and the development of microbiological analysis methods in fast, sensitive, efficient and reliable food for timely decision making in protection of the health of the population (Flores and Rojas, 2005; Quintero et al., 2012; Ledezma et al., 2013; Balbuena, 2014; Jorquera et al., 2015; FAO, 2018b).

ANALYSIS IN THE LABORATORY FOR THE DETECTION OF *SALMONELLA* SPP., AS PART OF CONTROL AND PREVENTION IN FISH AND OTHER FOODS

The analysis of food in the search for pathogenic microorganisms is considered an essential phase for the control of the safety and quality of food (Zadernowska and Chajęcka, 2012). Among the traditional methodologies of isolation and detection of *Salmonella* spp*.,* in foods which are based on the culture and identification through differential and selective means, biochemical and serological tests (Figure 1 and Table 1). Several methods have been reported around the world, some of them standardized and commonly used for this purpose, such as the US Food and Drug Administration (US FDA) in the manual of analytical bacteriology (BAM) by Andrews et al. (2017), the method developed by International Organization for Standardization (ISO) ISO 6579: 2002 or the MLG 4.09 method in its version of 2017 for the detection of *Salmonella* spp. in foods of the Department of Agriculture of the United States of America (USDA, 2017); and finally, the official method of national regulation in the Mexican Republic contemplated in the official Mexican standard NOM-210-SSA1-2014, for the detection of pathogens such as *Salmonella* spp., in food. Likewise, complementary or alternative molecular methods for the detection of pathogens have been developed, such as the polymerase chain reaction (PCR) in its multiple variants, immune enzymatic or proteomics such as electrophoresis and MALDI-TOF mass spectrometry (matrix-assisted laser desorption/ionization-time of flight) in order to reduce the analysis times presented by the phenotypic methods and to have an early detection; although its implementation is not universal due to the high cost and degree of specialization required for its application (Bou et al., 2011; Zadernowska and Chajęcka, 2012; Sparbier et al., 2012; Pavlovic et al., 2013; Soto et al., 2016; Cortes et al., 2017).

Foodborne diseases are a complex issue that impacts several social sectors, so detection and prevention are considered a joint effort between several social actors ranging from consumers, regulatory authorities, health, food industry and academia, whose actions lead to a decrease in the risks of contamination of food. To guarantee consumers a safe and hygienic food, it is necessary to control pathogenic microorganisms in all stages of the food chain and although the actions have focused on the production of healthy and safe food, using good hygiene practices such as good manufacturing practices, and quality and safety control measures, such as the implementation of hazard analysis and critical control point (HACCP), there is still much to be done as foodborne diseases continue to be responsible for high morbidity rates and in some cases of mortality, around the world, generating large losses for public health, animal health and the food industry (González and Rojas, 2005; Jorquera et al., 2015; WHO, 2018a).

REGULATION OF FOOD SAFETY AROUND THE WORLD OF FOOD AND FISH PRODUCTS FOR CONTROL AND PREVENTION OF SALMONELLOSIS AND OTHER FOODBORNE DISEASES

In food, and specifically fishery and aquaculture products, globalization and commercialization efforts have been directed towards guaranteeing food safety and quality, as well as environmental sustainability through different standards, codes, guidelines, and/or certifications to the global level, for example: general principles of food hygiene, microbiological criteria, risk assessment,

Table 1. Biochemical and serological identification tests for the isolation of *Salmonella* spp*.,* in the laboratory (Perilla et al., 2004; Andrews et al., 2017; Cortes-Sánchez et al., 2017).

Test	The reaction of species of *Salmonella* spp.*
Production of glucose acid (TSI)	+
Lysine decarboxylase (LIA)	+
H_2S in TSI and LIA	+
Hydrolysis of urea	-
Lysine decarboxylase broth	+
Methyl red	+
Voges-Proskauer	-
Malonate broth	-c
Indole production	-
Urease	-
Citrate metabolism	v
Mobility	+
Somatic polyvalent test	Agglutination+
Flagellar multi-purpose test	Agglutination+

LIA: Iron lysine agar; TSI: triple sugar iron agar. * +: 90% or more positive in 1 or 2 days; -: 90% or more negative in 1 or 2 days. v: Variable. b Mostly cultures of *S. arizonae* cultures are negative. The majority of *S. arizonae* cultures are positive.

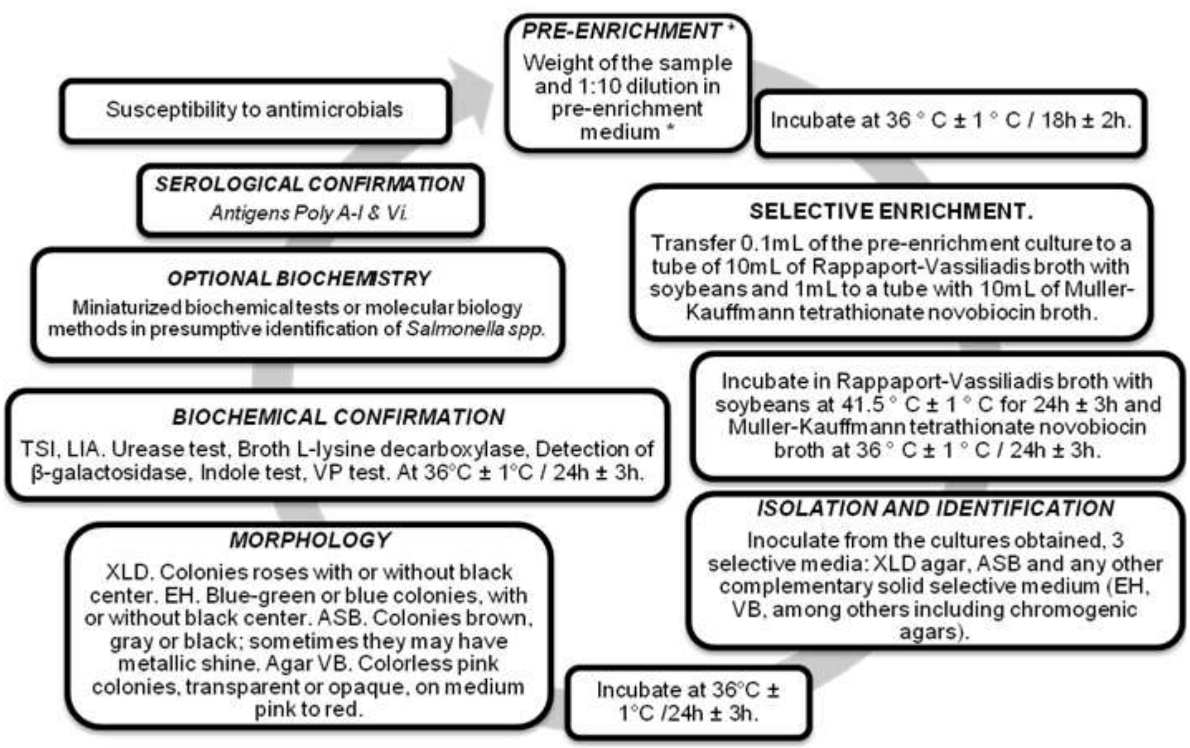

Figure 1. Method for the isolation and identification of *Salmonella* spp., in food. *The pre-enrichment medium will be according to the food under analysis; generally buffered peptone water is used. XLD: Xylose Deoxycholate Agar; ASB: Bismuth Sulfite Agar; VB: Bright Green Agar; EH: Hecktoen Agar; TSI: Triple Sugar Iron Agar, LIA: Iron Lysine Agar; VP: Vogues-Proskauer.
Source: Perilla et al. (2004); NOM-210-SSA1-2014; ISO 6579: 2002; Cortes-Sánchez et al. (2017).

HACCP system, ISO 22000, Safe Quality Food (SQF), British Retail Consortium (BRC), GlobalGAP, etc., generated and validated by different organizations like WHO, United Nations Organization for Food and Agriculture (FAO) through the Codex Alimentarius, World Organization for Animal Health (OIE), International

Organization for Standardization (ISO) and Global Food Safety Initiative (GFSI) (RECUA, 2018).

On the other hand, sanitary regulation and safety of food and fishery products in Europe has established different food safety legislation, such as the case of the European community that issued Regulation (EC) No 178/January 28, 2002 of the European Parliament establishing the principles and general requirements of food legislation, creating the European Food Safety Authority (EFSA) and establishing procedures related to food safety. Subsequently, through Regulation (EC) No 853/2004 of the European Parliament of April 29, 2004, the specific rules of hygiene of foods of animal origin including fish directed at company operators are instituted.

Likewise, on November 15, 2005, Commission Regulation (EC) No. 2073/2005 was issued, which is related to the microbiological criteria applicable to food products to serve as guidance on the acceptability of food products and their products manufacturing, handling and distribution processes; where for *Salmonella* spp., it indicates a criterion of "Absence in 25 g of product" using the method of analysis of the International Organization for Standardization (ISO) ISO 6579 likewise makes the application of procedures based on the principles of Hazard Analysis and Critical Control Point (HACCP) and other hygiene control measures.

In countries of the American continent such as Mexico, sanitary regulation through the Official Mexican Standard NOM-242-SSA1-2009, contemplates for fresh, refrigerated, frozen and processed fishery products, the physical, chemical and microbiological sanitary specifications, as well as test methods for your laboratory analysis. Indicating that for *Salmonella* spp., in all fishery products it must be "absent in 25 g of the product". While the Official Mexican Standard NOM-251-SSA1-2009, which refers to hygiene practices for the process of food, beverages or food supplements involve the minimum requirements of good hygiene practices that must be observed in the process of food, beverages or food supplements and their raw materials in order to avoid their contamination throughout their process, also including the HACCP system and guidelines for their application.

RESISTANCE TO ANTIMICROBIALS

Resistance is the mechanism obtained either naturally or acquired by which microorganisms decrease the action of antimicrobial agents on them when exposed to antimicrobials (antibiotics, antifungals, antivirals, antimalarials or anthelmintic). The resistant microorganisms are of cosmopolitan location and can be transmitted from person to person or between people and animals, even by food being the most common attributable causes to its spread of excessive, insufficient, indiscriminate and inappropriate use of these antimicrobial agents in the human clinic, agricultural and aquaculture production as prophylactic, therapeutic and growth promoters, in addition to poor sanitary conditions and inadequate handling in food production (FAO, 2002; Puig et al., 2011; Rivera et al., 2012; Cabello, 2004; WHO, 2018e).

There is a great concern around the world regarding public health due to the incidence of infections by microorganisms with this characteristic due to the increase in disability, death, prolongation of the disease, cost of health care due to the longer duration of hospitalizations and the need for more intensive care. It is estimated that approximately 500,000 people die each year globally due to causes related to antimicrobial resistance. In addition, this phenomenon affects food safety, food security and economic well-being as food is involved in the development and spread of antimicrobial resistance, and the presence of antimicrobial-resistant microorganisms in the food chain is a potential means of exposure (WHO, 2018a; FAO, 2018c).

Antimicrobial resistance in microorganisms can be intrinsic or acquire resistance by Novo mutations or by the transfer of genetic material (plasmids, transposons, and integrons) from other organisms. The ability to resist the action of antimicrobials is carried out through various mechanisms such as modification of the permeability of the membrane, expulsion of the compound by pumping excretion, enzymatic inhibition and modification of the attack target or alteration of the composition and the content of cell wall glycoproteins (Tafur et al., 2008; Becerra et al., 2009; Puig et al., 2011; Pérez and Robles, 2013).

Antimicrobial resistance is a growing threat to global public health and requires action by international organizations, the government sector, and society to reduce the incidence of this phenomenon (WHO, 2018a). Global action plans have been established by the World Health Organization (WHO) against antimicrobial resistance, where five strategic objectives are established: (1) Improve awareness and understanding of antimicrobial resistance; (2) Reinforce knowledge through surveillance and research; (3) Reduce the incidence of infections; (4) Optimally use antimicrobial agents and prepare economic arguments in favor of a sustainable investment that takes into account the needs of all countries; and (5) Increase investment in new medicines, diagnostic tools, vaccines and other interventions. Likewise, guidelines have been developed for the use of antimicrobials in animals intended for food production and thus avoid abuse and indiscriminate use (WHO, 2018b, FAO, 2018c). The Codex Alimentarius has developed scientifically based on guidelines and codes to manage antimicrobial resistance and its transmission along the food chain, such as risk analysis of foodborne antimicrobial resistance: CAC/GL 77-2011 and code of practice to minimize and contain antimicrobial resistance:

CAC/RCP 61-2005 (FAO, 2018c).

Salmonella spp*.* is one of the different pathogenic microorganisms isolated in foods that have shown resistance to different antimicrobials, affecting a large extent the food chain (Puig et al., 2011; Hur et al., 2012; WHO, 2018d). Resistance to antimicrobials by *Salmonella* spp., can be observed and transmitted mainly by consuming food contaminated with antibiotics or eating food contaminated with feces of animals or human carriers, who continue to suffer from the disease after various incomplete or failed treatments (Rivera et al., 2012). In the search for strains resistant to antimicrobials, several studies on animals and food have been carried out globally in order to improve the analysis, control, and prevention of infections by this bacterium, such as the case of food from fisheries where Rahimi et al. (2013) analyzed the prevalence and susceptibility to antimicrobials by different serotypes of *Salmonella* spp., such as *Salmonella Typhimurium, Salmonella enteritidis, Salmonella* Typhi*, Salmonella paratyphi* B, and *Salmonella newport* isolated in fishery products from three provinces (Bushehr, Hormozgan and Khuzestan) from the Persian Gulf on the southern coast of Iran, reporting the susceptibility of 19 isolates to different antimicrobial drugs using the disk diffusion method; the resistance to nalidixic acid was 47.4%, followed by resistance to tetracycline in 36.8%, streptomycin 15.8%, trimethoprim 15.8% and ciprofloxacin 5.3%. On the other hand, Budiati et al. (2013) conducted a study to determine the prevalence and resistance to antibiotics by *Salmonella* spp., in fish isolates such as: catfish (*Clarias gariepinus*) and tilapia (*T. mossambica*) obtained from wet markets and ponds fed chicken offal, eggs and commercial fish feed during the period of 2008 to 2009 in Malaysia; from a total of 172 samples (32 catfish and 32 catfish intestines, 32 tilapia carcass and 32 tilapia intestines and 44 water samples), the isolation of seven *Salmonella* serovars in catfish 9/32 (28.1%), tilapia 14/32 (43.8%) and water samples 11/44 (25%) were reported. Isolated serotypes include *Salmonella albany, Salmonella agona, Salmonella corvallis, Salmonella stanley, S. Typhimurium, Salmonella mikawashima* and *Salmonella bovis-mobificans*. The sensitivity of these isolates to different antibiotics was for chloramphenicol (37.2%), clindamycin (100%), rifampicin (90.7%), spectinomycin (27.9%) and tetracycline (67.4%).

Finally, Elhadi (2014) carried out the analysis of the proportion of imported frozen fish contaminated with *Salmonella* spp. between retail food stores and supermarkets in the Eastern Province of Saudi Arabia wherein a total of 225 fish samples analyzed which included 75 of tilapia from India and Thailand; the results showed that 30 of these tilapia samples were positive for *Salmonella* spp. with 20 and 22 isolates, respectively. The isolates also showed resistance to antibiotics such as tetracycline, ampicillin and clavulanic acid-amoxicillin. In all the previous studies, it is concluded that the increase and spread of this antimicrobial-resistant food pathogen is related to the wide use of antimicrobial agents, in human, veterinary medicine, livestock production and aquaculture as prophylactic, therapeutic or growth promoters; in addition to the fact that the increase of the antimicrobial resistance phenomenon by *Salmonella* spp., could restrict the therapeutic options for clinical cases that appear to be derived from the transmission of food, so it is recommended that food control authorities generate and implement in a robust manner regular surveillance systems for this pathogen transmitted through fish and aquaculture products destined as food for human consumption and sharing the information globally to improve the effectiveness of the control programs.

The monitoring of antimicrobial resistance by *Salmonella* spp., through the development of monitoring networks between countries for the detection of resistant bacteria, can improve epidemiological studies for the control of outbreaks or epidemics in humans around the world; likewise, the control of this phenomenon involves different actions such as sanitary and hygienic regulation in agricultural, fishing and aquaculture production, the generation and implementation of educational plans for human, veterinarian, and personnel working in the different phases of the food chain, the rationalized use and rotation of drugs are useful for safeguarding food safety and for combating antimicrobial resistance (Puig et al., 2011; Hur et al., 2012; Rivera et al., 2012; FAO, 2018c; WHO, 2018d).

CONCLUSION

Foodborne diseases are a major global public health problem due to their incidence, mortality and global threat due to resistance to antimicrobials by causal agents of biological origin that put at risk the human and animal health and food safety.

Salmonella spp. is considered a food pathogen frequently related to outbreaks of foodborne diseases together with the fact that different serotypes of clinical isolates and foods have been shown to be resistant to antimicrobials commonly used in human therapeutics.

Reports around the world continue to indicate the isolation of resistant pathogens, so that international health and food organizations, government authorities, the food industry and academia must continue actions in surveillance, regulation and promote to avoid the indiscriminate and inappropriate use of antimicrobials for therapeutic purposes, prophylactic in human and animal health as well as in the production of food.

Fish is considered a highly nutritious food by their contents: water, proteins, lipids, vitamins and minerals, but also too perishable and susceptible to deterioration and contamination by pathogenic microorganisms such as *Salmonella* spp., during any phase of the food chain (primary production, processing, conservation, distribution, commercialization, among others), improper hygiene practices were mainly derived.

Tilapia is a group of fish widely known, produced and intended for human consumption for its adaptation and tolerance to environmental and food conditions of growth in culture, as well as being a source of proteins, vitamins, lipids and minerals.

Tilapia is marketed in different presentations (fresh whole, gutted, fillets, refrigerated, frozen, among others) according to the preference of the consumer; this fish is obtained through capture fisheries and aquaculture throughout the world, with the Asian countries being the main producers. And like other fish in their production, capture is susceptible to contamination and deterioration by various chemical and biological agents (among these bacteria of the genus *Salmonella* spp.) derived mainly to poor hygiene practices in fishing activities, aquaculture, processing and manipulation prior to consumption, turning them into high-risk food products for the health of the consumer.

For several years, different international organizations such as the WHO, Codex Alimentarius, International Organization for Standardization and others around the world have generated recommendations, guidelines, certifications concerning fish and products in order to produce, distribute and market food of nutritional quality and protect public health.

Contamination of food can occur in any link of the food chain turning them into carriers of diseases where the causative microorganisms have the ability to resist different antimicrobials, some of them commonly used in therapeutic treatments. World reports indicate that some of the factors involved in the emergence and increase of resistance to antimicrobials is the indiscriminate use of antimicrobials in human and animal health as well as in food production; the isolation of microorganisms resistant to antimicrobials from clinical cases and food continues to increase, generating a priority concern and challenge at the global level in developing guidelines and programs for action focused on control and prevention jointly between different social actors such as different international organizations in the field of health and nutrition, government agencies, academics, primary producers of food, food industry and general population in order to generate awareness of regular surveillance of the use of antimicrobials, which are a factor involved in the safety of food, including products from fisheries and aquaculture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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