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Review Article

Food Surveillance of *Salmonella* spp. and Impacts on Public Health and Brazilian Economy

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Abstract

Salmonella is a bacterial genus with a major economic and public health impact, responsible for salmonellosis, a foodborne infection that affects millions of people worldwide. Capable of multiplying in food and water, it is one of the main causes of food- and water-borne diseases. In Brazil, recurrent outbreaks result in hospitalizations and economic losses, mainly in products of animal origin, highlighting the need for rigorous and permanent control and prevention measures. Cooperation between government, industry and consumers is essential to ensure food safety and minimize impacts on public health and the economy. Contamination control involves hygiene practices, food education and public health strategies to avoid cross-contamination. Another challenge is antimicrobial resistance, which makes it difficult to treat infections, increases morbidity and mortality rates and affects health systems and industry. Advanced technologies, such as PCR, biosensors and genetic sequencing (NGS), have improved detection, strengthening outbreak response and food safety. Based on a review of the literature from the last 10 years, this study addresses the pathogenic mechanisms of *Salmonella* and its involvement in foodborne outbreaks. Brazil has made progress in regulations, food surveillance and the use of new technologies. These actions reduce the incidence of salmonellosis and promote food safety, reinforcing ongoing efforts in public health and sustainable production.

Keywords: *Salmonella*; Brazil; Food Safety

Introduction

Salmonella is a genus of bacteria that has been extensively researched due to its significant impact on public health and the economy. Discovered at the end of the 19th century, it is known for causing salmonellosis, a foodborne infection that affects millions of people globally each year. In Brazil, this condition represents a continuous public health challenge, with recurring outbreaks leading to hospitalizations and, occasionally, deaths.

Salmonella has a significant economic impact in Brazil, as food contamination, particularly in products of animal origin, leads to substantial losses in the production chain. These losses include the costs of medical treatments, epidemiological investigations, and recalls of contaminated products. Furthermore, the need to implement stringent control and prevention measures increases production costs for the food industry, affecting market competitiveness.

Microbiological integrity is crucial in food production. Current research emphasizes the importance of proper handling practices and sanitary controls to reduce the occurrence of *Salmonella* infections. Studies [31] indicate that measures such as using potable water, controlling raw materials, training food handlers, ensuring hygiene, and using safe temperatures for food storage are effective in preventing water - and foodborne diseases (DTHAs). In 2022, a study [28] highlighted that microorganism presence could result from inadequate practices at various stages, from slaughter to processing and marketing, as well as cross-contamination of other foods.

Understanding the factors contributing to the dissemination of this bacterium is essential for developing effective control and prevention strategies. Therefore, this review article aims to provide a comprehensive overview of *Salmonella*, including its characteristics, virulence, pathogenicity, antimicrobial resistance, outbreak incidence, and recent advances in control and prevention measures. It highlights its impact on public health and the economy, based on scientific literature from the past decade.

Methodology

This study was based on a review of scientific articles to compile this review article, using the following keywords: *Salmonella*, food, public health, and economy. Searches were conducted in the following databases: Portal CAPES, PubMed, Scopus, and Google Scholar. As inclusion criteria, only peer-reviewed articles published in the last 10 years in Portuguese, English, or Spanish were considered. Studies that did not meet these criteria were excluded from the review, resulting in 28 scientific articles that supported the writing of this review on *Salmonella*.

Etiological Agent: *Salmonella* and its main characteristics

The genus *Salmonella* was first identified in 1885, named after the pathologist Daniel Salmon. As a member of the *Enterobacteriaceae* family, it consists of non-spore-forming, often flagellated, facultative anaerobic, Gram-negative bacilli. These bacteria can ferment glucose and other sugars and decarboxylate amino acids such as lysine [18,23].

The genus *Salmonella* includes three species and six subspecies: *S. subterranea*, *S. bongori*, and *S. enterica* (with the subspecies *enterica, salamae, arizonae, diarizonae, houtenae,* and *indica*). To date, more than 2.600 serotypes of *Salmonella enterica* have been identified. Globally, after *Enteritidis*, *Salmonella Typhimurium* is the second most frequently isolated serotype, including its monophasic variant S. 4,[5],12:i:. This variant has become one of the five most prevalent serovars among human clinical isolates [17,24,32].

Within the genus *Salmonella*, isolates are classified through a series of tests to determine biochemical properties [24]. The current distribution of serovar numbers by species and subspecies is presented below: (Table 1).

Species and Subspecies	No
Salmonella enterica subsp. enterica	1586
Salmonella enterica subsp. salamae	522
Salmonella enterica subsp. arizonae	102
Salmonella enterica subsp. diarizonae	338
Salmonella enterica subsp. houtenae	76
Salmonella enterica subsp. indica	13
Salmonella bongori	22
Total	2659

Table 1: Current number of serovars by species and subspecies of *Salmonella.*

Source: Issenhuth-Jeanjean, et al., (2014).

The cellular composition of *Salmonella* includes lipids, lipopolysaccharides, proteins, and lipoproteins. The lipopolysaccharide and lipid portion of the cell wall contain an endotoxin, responsible for the bacterium's biological effects. The polysaccharides in the common core of the endotoxin are referred to as somatic (O) antigens. *Salmonella* also possesses flagellar (H) antigens composed of flagellin subunits, which form the filamentous portion of bacterial flagella and are presented as phase I and/or phase II H antigens. Additionally, there is a capsular (Vi) antigen, present only in *Salmonella Typhi*, though it is occasionally identified in *Salmonella Paratyphi C* and *Salmonella Dublin*. Evidence also suggests that *Salmonella* can produce fimbriae, which are important for maintaining and surviving in its host and environment [23].

The optimal pH range for *Salmonella* is 3.8 to 9.5, with an optimal temperature for multiplication between 6.6°C and 6.8°C, favoring a slightly acidic to near-alkaline environment. Consequently, these factors can inhibit bacterial activity [18]. *Salmonella* is sensitive to heat, unable to survive at temperatures above 70°C. With these physiological characteristics, this microorganism can survive and multiply in a wide variety of foods. Infectious agents, including viruses, fungi, parasites, and bacteria, account for nearly 90% of health issues related to food consumption. These problems are attributed to production, handling, transportation, distribution or sales [16].

Salmonellosis is one of the leading causes of morbidity and mortality worldwide, colonizing both animals and humans and being present in the environment. *Salmonella* is one of the most important foodborne pathogens, with animals and animal-derived foods being the primary routes of transmission to humans. This bacterium causes severe clinical manifestations, including acute gastroenteritis and typhoid fever [25].

There are various diseases caused by *Salmonella* spp., classified under the broader term salmonellosis, which is divided into two groups. The first group causes typhoid fever, while the second causes gastrointestinal syndromes, the latter being the most common among humans. Enteric fevers are caused by typhoidal salmonellosis, which includes two types of fever, each caused by different types of *Salmonella* [30].

Salmonella spp. is excreted in large numbers in feces, contributing to soil and water contamination. In the environment, it can persist for long periods, particularly in organic matter. It can remain viable for years, especially in dried feces, surviving over 28 months in bird feces, 30 months in cattle manure, 280 days in cultivated soil, and 120 days in pastures. It is also found in sewage effluents due to fecal contamination. Globally, *Salmonella* is recognized as the primary etiological agent of food- and waterborne diseases [2].

Virulence factors and pathogenic mechanisms

The vast majority of *Salmonella* serotypes are pathogenic to humans, with two species in the *Salmonella* genus being the main causes of salmonellosis in humans: *Salmonella enterica* and *Salmonella bongori*. The former is more relevant to public health and is composed of six subspecies, particularly *S. enterica*. The serotype *Salmonella Typhi* is the etiological agent of typhoid fever, while the serotype *Salmonella Paratyphi* is associated with paratyphoid fevers. Other serotypes of *S. enterica* related to food- and waterborne diseases (DTHAs) typically cause enterocolitis or non-typhoidal salmonellosis [8].

The virulence of pathogenic *Salmonella* spp. serotypes for humans and animals is linked to their ability to establish a successful infection in a host. This requires the coordinated expression of various genes responsible for synthesizing virulence or pathogenicity factors. These factors enable the bacteria to colonize and invade tissues, escape adverse conditions in the gastrointestinal tract, and evade the host's immune responses. The complex invasion process is mediated by the expression products of various chromosomal genes, while the ability to grow inside host cells depends on the presence of virulence plasmids [22].

Salmonella employs pathogenic mechanisms that cause damage to susceptible hosts when the immune system is overwhelmed. In such cases, virulence is essential for the onset of disease in the hosts [23].

Sintomatologia
Symptomatology

Salmonellosis is cosmopolitan in distribution, affecting all age groups, both in developed and developing countries, constituting an important public health problem. It has been one of the main causes of foodborne diseases, transmitted mainly through the oral-fecal route, ingestion of contaminated water and food, or contact with infected animals [6].

The ingestion of food contaminated with *Salmonella* spp. can result in outbreaks of foodborne illnesses, with symptoms ranging from general malaise to severe diarrhea, vomiting, and even severe cases that can lead to death. The clinical forms are represented by acute gastroenteritis – the most common – and enteric fevers (typhoid and paratyphoid fever) [14].

The manifestation of the disease depends on various factors, including the involved serovar, the associated virulence factors, the infectious dose, the age group, and the host's immune status. Children, the elderly, and immunocompromised individuals tend to be more susceptible and present with more severe clinical symptoms, including sepsis [7,20].

The typhoidal serovars differ substantially from the gastroenteritis associated with non-typhoidal serovars. The former has a longer incubation period, ranging from 5 to 9 days, and the same applies to the symptoms, as the fever persists for approximately three weeks. While gastroenteritis caused by non-typhoidal serovars is characterized by a rapid onset, a short incubation period ranging from 12 to 72 hours, and a duration of no more than 10 days [7].

In typhoid fever, common symptoms include chills, abdominal pain, hepatosplenomegaly, nausea, diarrhea or constipation, headache, anorexia, and dry cough. In immunocompromised patients, the disease can worsen if not treated, developing complications such as gastrointestinal bleeding and intestinal ulcers. Between 3% and 5% of patients become chronic carriers, with infection in the gallbladder, and start to intermittently eliminate the agent through feces and urine [20].

Enteric fever, on the other hand, individuals affected generally present with gastroenteritis, often self-limiting, characterized by diarrhea, abdominal cramps, nausea, abdominal cramps, vomiting, and fever. In individuals more susceptible to infection, it can extend beyond the intestine and cause bacteremia, characterized by fever in the absence of diarrhea [7,20].

Involvement in waterborne or foodborne diseases

Salmonella is a pathogen of great significance in water and foodborne diseases. Contamination frequently occurs through the consumption of animal-derived foods, such as meat, eggs, and milk, that have not been properly cooked. Vegetables and fruits can also be contaminated when washed with contaminated water. It is seen as one of the major foodborne pathogens, with high risks to human health [12].

According to data from the Ministry of Health, between 2012 and 2021, there were 6,347 outbreaks of DTHA, with 104,839 patients and 89 deaths in Brazil. Of these cases, Salmonellosis accounted for 11.2%. Thus, being the third leading cause of foodborne illnesses in the country during this period. Of the confirmed cases, residences were the locations where DTHA occurred most frequently, and the most incriminated foods were mixed foods [5].

In Brazil and around the world, *Salmonella* is among the main agents involved in foodborne illnesses. Outbreaks are frequently associated with the consumption of contaminated water and also through the consumption of mixed foods, undercooked or raw meat, unpasteurized milk and dairy products, eggs and their derivatives, contaminated fruits and vegetables [5]. Among the outbreaks caused between 2007 and 2015 by *Salmonella* spp., 67.5% were due to *Salmonella Enteritidis* and 7.5% to *Salmonella Typhi* [4].

According to the review conducted by [13], covering the period from 2000 to 2018, *Salmonella* was the main cause of foodborne illnesses in Brazil (22.8%), with mixed foods being the most prevalent (31.6%) and residences being the most common locations (45.6%). Eggs and egg products were associated with 6.9% of the cases, ranking seventh as a vehicle of foodborne diseases, according to the articles researched by the authors.

In addition to *Salmonella*, *Escherichia Coli* is the main agent involved in DTHA outbreaks in Brazil according to data from the Ministry of Health (MS). Between 2009 and 2018, 6,809 DTHA outbreaks were reported by the Health Surveillance Secretariat, affecting 634,568 people, resulting in 120,584 cases of illness, 16,632 hospitalizations, and 99 deaths in Brazil. The data from the Ministry of Health confirm that in the majority of outbreaks (23.4%), the main etiological agent was *Escherichia Coli*, followed by *Salmonella* spp. (11.3%) and Staphylococcus aureus (9.4%) [3].

Synergism with other bacterial species

There is evidence that *Salmonella* is one of the main biofilm-forming agents and that it can even form biofilms together with other bacterial species, such as *Escherichia coli* and Listeria monocytogenes, increasing collective resistance to disinfectants and antibiotics. Biofilms are well-structured communities of microorganisms that can adhere to the surfaces of utensils and equipment in the food industry, which are fixed through an extracellular matrix of polysaccharides [10].

According to [27], there is a possibility of *Salmonella* forming biofilms on surfaces such as plastic, rubber, glass, and stainless steel. The process of biofilm formation can develop pathogenic microorganisms due to failures in hygiene and cleaning procedures, causing significant harm to the food industry and serious health problems for consumers.

Main risks associated with food processing

One of the main risks associated with food processing involving *Salmonella* is cross-contamination that can occur through contact with contaminated equipment and surfaces, which can transfer the bacteria to uncontaminated food. Moreover, during food processing, the handling stages are conducive to contamination occurring [15].

The handling of raw foods is a critical point for the contamination of other foods by *Salmonella*. Improper or insufficient cooking of animal-derived foods may not eliminate *Salmonella*, resulting in infections. And finally, storing food at inadequate temperatures can allow the multiplication of *Salmonella* in the food. Furthermore, the ability of *Salmonella* sp. to adapt to a variety of environmental conditions, including different temperatures, pH levels, and low water activity, poses challenges for the food industry [9].

Antimicrobial resistance involving *Salmonella*

Antimicrobial resistance is a growing concern in global public health, and *Salmonella* is one of the most relevant pathogens in this context. The ability to develop resistance to multiple antibiotics complicates the treatment of infections, increases morbidity and mortality, and imposes significant challenges to the healthcare system and the food industry. As pointed out by [19], the increasing rise in antimicrobial resistance is related to the indiscriminate use of antibiotics in various sectors of human and veterinary medicine. And thus, generating a huge impact on human health and the economy around the world.

Salmonella is a Gram-negative bacterium that has a structure of peritrichous flagella, lacks a capsule, and is not sporulated. This type of bacterium also has pili and a nucleoid where DNA is present, as well as cytoplasm, ribosomes, a plasma membrane, a cell wall, and a plasmid [8]. However, *Salmonella* can acquire antimicrobial resistance through various mechanisms, including genetic mutation, horizontal gene transfer, and efflux pumps. However, *Salmonella* resistance is a complex issue that can be caused by various factors, with gene transfer being the most dynamic and widely researched [11].

Antimicrobial resistance in *Salmonella* has direct implications for public health and the economy. In Brazil and other parts of the world, outbreaks of multi-drug resistant salmonellosis have been increasingly recorded, resulting in longer and more complex treatments, higher hospital costs, and increased mortality rates. Given that raw chicken is a good reservoir for *Salmonella*, the increase in poultry production and consumption has been accompanied by a rise in foodborne illnesses due to *Salmonella* infection traced back to chicken products [26].

Recent studies show that antibiotic-resistant strains of *Salmonella* are frequently isolated from animal-derived foods, such as poultry and swine, due to the indiscriminate use of antimicrobials in livestock farming. For example, resistance to antibiotics such as ampicillin, tetracycline, and sulfonamides has been frequently reported. However, it is important to emphasize the role of the veterinarian in terms of their responsibility throughout the entire animal food production chain [19]. Having as its main objective to control chemical and biological hazards, providing a product of quality and safety within the standards required by law.

However, antimicrobial resistance in *Salmonella* is a significant threat to public health and food safety on a global scale. The multidisciplinary approach, which includes the rational use of antibiotics, the improvement of hygiene practices, and the development of new technologies, is essential to mitigate this threat. The collaboration between governments, industry, and the scientific community is crucial to design.

Incidence of *Salmonella* outbreaks in brazil in recent years

In recent years, the occurrence of salmonellosis outbreaks in Brazil has raised concerns both in terms of public health and economic impacts. *Salmonella* is one of the main pathogens associated with foodborne diseases, and outbreaks of this bacteria can result in serious health problems for the population and significant losses for the food industry (World Health Organization, 2020). According to the Pan American Health Organization, 2020, annually, foodborne diseases affect one in ten people, causing serious consequences, especially for children under five years old, as the consumption of contaminated food can increase the risk of mortality.

In studies conducted in Brazil [19], it was demonstrated that the main locations where DTHAs occur are residences (34%), events (19%), and restaurants/bakeries (17%). The Ministry of Health in 2024 provided the outbreak indices of DTHAs in Brazil, confirming the trend indicated in previous studies, where (34%) of the outbreaks that occurred from 2014 to 2023 took place in residences, followed by (14.6%) in restaurants and (12.5%) in daycare centers/schools. It is noted that there was a change in the locations where the outbreaks occurred, highlighting the need for continuous training in food handling in these places. Additionally, the lack of information among the population about food storage and preparation in their homes becomes a determining factor for the occurrence of the high number of outbreaks in residences.

Among the main agents involved in the outbreaks, *Salmonella* was in first place, followed by *E. coli* and *S. aureus* [19]. In 2024, according to the Ministry of Health, *Salmonella* is identified as the third most common etiological agent in DTHA outbreaks, representing (9.6%). In this study, *E. coli* is the most identified with (34.8%), followed by *Staphylococcus* spp. with (9.7%).

Salmonella outbreaks have significant economic impacts, especially for the brazilian poultry industry, which is one of the largest in the world. Despite being the sector of agribusiness that invests the most in technologies to monitor poultry farms, salmonellosis continues to be a threat to poultry farming and a concern for public health. Brazil currently holds a high and respected position in broiler chicken production, and this is mainly due to the sanitary condition of its products. The country serves an increasingly demanding consumer market, and it is the responsibility of veterinarians, producers, and regulatory bodies to pay attention to the health of the birds, consequently ensuring food safety for both the domestic and foreign markets [29].

However, the incidence of salmonellosis outbreaks in Brazil in recent years underscores the importance of continuous and rigorous measures to control and prevent *Salmonella* contamination. The impact of these outbreaks on public health and the economy highlights the need for a collaborative effort between the government, industry, and consumers to ensure food safety.

Factors frequently overlooked in the prevention and control of *Salmonella*

Inadequate handling practices that result in cross-contamination between raw and cooked foods can facilitate the spread of *Salmonella*. The lack of care with the personal hygiene of food handlers is also an important factor. Despite the existence of regulations that govern the absence of *Salmonella* for food to be considered safe, some studies conducted in Brazil have detected the presence of this bacteria, indicating the need for improvements in the hygienic-sanitary quality of food and the expansion of the inspection of these products [28].

In the food industry, some factors should not be neglected for the prevention and control of *Salmonella*, such as temperature control for food storage or preparation, hygiene and sanitation of facilities, handling practices in food preparation through employee training, quality control in the selection of ingredients, equipment maintenance, waste management, process monitoring and control, traceability, and product recall.

Poorly trained employees may not follow proper food hygiene and safety practices. Regular training is necessary to ensure that everyone understands and implements the correct procedures. The lack of maintenance and inadequate cleaning can lead to the growth and spread of *Salmonella*. Improper waste management can result in cross-contamination and attract pests, which can transmit *Salmonella* to food. The absence of effective monitoring and control systems can allow conditions favorable to the growth of *Salmonella* to go unidentified and uncorrected in time. The lack of effective traceability systems can hinder the identification and removal of contaminated products from the market in the event of an outbreak. The implementation of robust tracking and recall processes is essential.

However, attention to these factors can significantly help in the prevention and control of *Salmonella* in the food industry, reducing the risk of contamination and ensuring food safety.

Prevention and control of foodborne diseases (FBDs) caused by *Salmonella*

For the control and prevention of diseases caused by *Salmonella*, proper hygiene is essential, especially in the food sector. In addition to the hygienic practices carried out by industries by the handlers, there is also a need for domestic hygiene, such as the proper cleaning of food, storage, preservation methods, cleaning of utensils and preparation areas, as well as care during meal preparation, avoiding direct contamination and cross-contamination between raw and cooked foods [4].

Health education actions are recommended, highlighting personal hygiene habits, especially the correct handwashing among people who handle food, observing care in the preparation, handling, storage, and distribution of food. Among the main prevention strategies, the following should be considered: the selection of raw materials, utensils, and equipment that are carefully sanitized; the provision of potable water and an adequate waste and sewage treatment system; the adoption of good manufacturing practices and the implementation of the HACCP system (Hazard Analysis and Critical Control Points); the removal of asymptomatic carriers from

the production area; and appropriate preservation and transportation methods. All these actions are in accordance with the recommendations of public health authorities worldwide [4].

Inspection and health surveillance play a fundamental and multifaceted role in the prevention of foodborne diseases. More than 250 diseases are transmitted through food, and their incidence has increased considerably in recent decades due to the globalization of the food market and changes in eating habits [21].

Advances in control and prevention measures for *Salmonella*

In the last five years, there have been significant advances in control and prevention measures for *Salmonella*. Brazil has updated and reinforced regulations and standards related to food safety, including the Brazilian Standard for Standard Operating Procedures (POP) and the revision of standards by the Ministry of Agriculture, Livestock, and Supply (MAPA), which include specific measures for *Salmonella* control [5].

The country has intensified food monitoring and surveillance, especially for high-risk products such as meat and eggs. Monitoring programs, such as the Foodborne Disease Surveillance System, have contributed to the early detection and control of outbreaks. And there have been advances in diagnostic technologies, such as Polymerase Chain Reaction (PCR) methods and genetic sequencing techniques, which allow for faster and more accurate identification of *Salmonella* in food samples. Still on a global level, technological innovations are gaining prominence in advances in rapid and sensitive detection technologies, such as biosensors and portable analysis devices, which have enabled faster identification of *Salmonella* in food and production environments. The use of advanced DNA sequencing techniques, such as next-generation sequencing (NGS), has improved the ability to track and understand the epidemiology of *Salmonella* outbreaks. Furthermore, it is worth highlighting the promising progress in the development of vaccines that can reduce the *Salmonella* load in the food chain [1].

Meanwhile, this entire process, along with the increase in global regulation and improvements in production processes, reflects a continuous effort to enhance food safety and reduce the incidence of *Salmonella* infections, both in Brazil and worldwide.

Final Considerations

Salmonella has a considerable impact on public health and the economy, as evidenced by a wide range of scientific studies from the past ten years. Regarding public health, *Salmonella* infections are responsible for a significant number of cases of gastroenteritis, hospitalizations, and even deaths, placing a considerable burden on healthcare systems. Economically, the impact is significant, considering food product recalls and damage to companies' reputations, leading to a loss of consumer trust and consequently causing substantial financial losses.

The incorporation of technologies such as PCR, biosensors, and NGS marks an important progress in the identification of *Salmonella* in food. These tools not only enhance the accuracy and speed of detections and identification of the agent but also improve the ability to respond to contamination outbreaks, benefiting food safety and public health. The use of these technologies by the food industry is crucial to ensure product safety and reduce the risks of *Salmonella* contamination.

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