UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Posgrados

Contribution to the knowledge of the physiology, involved foods, and control of nontyphoidal *Salmonella enterica*

Mecanismo de Titulación: TESIS DOCTORAL

Esthela Teresa Guerrero Villegas

Sonia Zapata Mena, PhD
Director de Trabajo de Titulación

Trabajo de titulación de posgrado presentado como requisito
para la obtención del título de PhD en Microbiología

Quito, 10 de diciembre de 2021

UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

COLEGIO DE POSGRADOS

HOJA DE APROBACIÓN DE TRABAJO DE TITULACIÓN

Contribution to the knowledge of the physiology, involved foods, and control of nontyphoidal *Salmonella enterica*

Esthela Teresa Guerrero Villegas

Nombre del Director del Programa:	Gabriel Trueba Piedrahita
Título académico:	PhD
Director del programa de:	Doctorado en Microbiología

Nombre del Decano del colegio Académico:	Carlos Valle
Título académico:	PhD
Decano del Colegio: COCIBA	Ciencias Biológicas y Ambientales

Nombre del Decano del Colegio de Posgrados:	Hugo Burgos
Título académico:	PhD

Quito, 10 de diciembre 2021

© DERECHOS DE AUTOR

Por medio del presente documento certifico que he leído todas las Políticas y Manuales de la Universidad San Francisco de Quito USFQ, incluyendo la Política de Propiedad Intelectual USFQ, y estoy de acuerdo con su contenido, por lo que los derechos de propiedad intelectual del presente trabajo quedan sujetos a lo dispuesto en esas Políticas.

Asimismo, autorizo a la USFQ para que realice la digitalización y publicación de este trabajo en el repositorio virtual, de conformidad a lo dispuesto en la Ley Orgánica de Educación Superior del Ecuador.

Nombre del estudiante:	Esthela Teresa Guerrero Villegas
Código de estudiante:	00140985
C.I.:	1706052428
Lugar y fecha:	Quito, 10 de diciembre de 2021.

ACLARACIÓN PARA PUBLICACIÓN

Nota: El presente trabajo, en su totalidad o cualquiera de sus partes, no debe ser considerado como una publicación, incluso a pesar de estar disponible sin restricciones a través de un repositorio institucional. Esta declaración se alinea con las prácticas y recomendaciones presentadas por el Committee on Publication Ethics COPE descritas por Barbour et al. (2017) Discussion document on best practice for issues around theses publishing, disponible en http://bit.ly/COPETheses.

UNPUBLISHED DOCUMENT

Note: The following graduation project is available through Universidad San Francisco de Quito USFQ institutional repository. Nonetheless, this project – in whole or in part – should not be considered a publication. This statement follows the recommendations presented by the Committee on Publication Ethics COPE described by Barbour et al. (2017) Discussion document on best practice for issues around theses publishing available on http://bit.ly/COPETheses.

AGRADECIMIENTOS

En primer agradezco a Dios, por darme la fuerza cada día para continuar.

Agradezco a mi familia: a mi esposo Carlos, a mis hijos Carlos y Daniel, y a mi mami, por haberme acompañado y apoyado a lo largo de esta travesía del Doctorado.

Agradezco a la Universidad San Francisco y al Colegio de Posgrados, por la oportunidad de cursar este posgrado.

A mi Comité: Sonia Zapata, Gabriel Trueba, Antonio Machado y Christian Vinueza, por el tiempo invertido en trabajar conmigo, corregir y comentar mi trabajo.

A la Coordinación del Doctorado en Microbiología, constituida por Gabriel Trueba y Patricio Rojas, por su apoyo y guía.

Al Instituto de Microbiología y a su staff por facilitarme el uso de las instalaciones, el material y recursos que necesité para mi investigación.

A la empresa avícola propietaria de las granjas de pollos y plantas procesadoras en donde realizamos los ensayos; a todo el personal que gentilmente colaboró en esta investigación.

Al laboratorio de bacteriología de la Facultad de Medicina Veterinaria y Zootecnia de la Universidad Central del Ecuador, y al laboratorio de caracterización de nanomateriales, CENCINAT, de la Universidad de las Fuerzas Armadas ESPE, Ecuador.

A mis amigos, por esa mano extendida, por las palabras oportunas y el abrazo cálido: Sully Márquez, Carlita Torres, Jime Altamirano, Any Cárdenas, Sarita Cifuentes, Vero Barragán, Lore Montero, Diana Calderón, Ligia Luna, Fer Loayza, Fer Zurita, Gaby Vasco, Deysi Parrales, Belén Prado, Daniel Garzón.

A los estudiantes de la Maestría en Microbiología de la USFQ, clase 2020.

A las estudiantes que colaboraron conmigo en el trabajo de laboratorio: Karen Pacheco, Brenda Tito, Camila Barahona y Emilene Erazo.

RESUMEN

A nivel mundial, *Salmonella* no tifoidea (SNT) es la principal causa de enfermedades bacterianas transmitidas por los alimentos. SNT ha sido aislada de una gran variedad de productos, pero más frecuentemente, de alimentos de origen animal; sin embargo, su creciente presencia en frutas y vegetales también constituye un riesgo de salmonelosis porque estos alimentos suelen consumirse crudos. Aunque la salmonelosis de origen alimentario es generalmente leve, se estima que la carga económica global asociada a salmonelosis humana es mayor a 2600 millones de dólares anuales; por esta razón, las normas sanitarias son muy estrictas en cuanto a la baja o nula tolerancia de SNT en alimentos. El incumplimiento de las normas en cuanto al control de este patógeno en la industria de alimentos ocasiona pérdidas económicas importantes para toda la cadena productiva. A este panorama hay que añadir la preocupación mundial por el incremento de la resistencia antimicrobiana (RAM) en bacterias, en vista de que hay numerosos reportes de SNT que presentan resistencia a varios antimicrobianos. En este contexto, esta investigación tuvo como componentes: (1) una revisión sistemática de publicaciones sobre alimentos en los que se ha reportado SNT, sus serotipos y patrones de RAM en América Latina; (2) la determinación de la capacidad de *Salmonella* de crecer en materia faecal fresca de pollo, con el fin de conocer su comportamiento una vez que es excretada de un hospedador animal, lo que puede repercutir en la contaminación de alimentos; y (3) el aislamiento de mezclas de bacteriófagos de aguas de desecho, y su aplicación en una granja avícola comercial, como parte de una estrategia de búsqueda de sustitutos de los antibióticos. De este trabajo se puede concluir que, con el aumento de la producción de alimentos a gran escala, y por la capacidad que tiene SNT de multiplicarse en la materia faecal fuera del hospedador, el uso de estiércol como fertilizante sin un tratamiento adecuado contribuye a que este patógeno contamine productos agrícolas; ante este riesgo son, necesarias

acciones de control apropiadas para evitar su diseminación e ingreso a la cadena alimenticia. Por otro lado, con los resultados obtenidos se puede afirmar que los bacteriófagos constituyen una alternativa viable para reemplazar a los antibióticos contra *Salmonella* en la industria avícola; sin embargo, a futuro es necesario monitorear la propagación de bacterias resistentes a los bacteriófagos.

Palabras clave: *Salmonella* no tifoidea, alimentos, América Latina, materia faecal de pollo, bacteriófagos de *Salmonella*, granjas avícolas.

ABSTRACT

Globally, nontyphoidal *Salmonella* (NTS) is the leading cause of foodborne bacterial diseases; it has been isolated from a wide variety of products, but more frequently from foods of animal origin; however, its increasing presence in fruits and vegetables also constitutes a risk of salmonellosis because these foods are usually eaten raw. While foodborne salmonellosis is generally mild, the global economic burden associated with human salmonellosis is estimated to be greater than 2.6 billion dollars annually; for this reason, sanitary standards are very strict regarding the low or null tolerance of NTS in food. The non-observance of the regulations in the control of this pathogen in the food industry gives rise to significant economic losses for the entire production chain. To this panorama must be added the worldwide concern about the increase in antimicrobial resistance (AMR) in bacteria, given that there are numerous reports of multidrug-resistant NTS. In this context, this research had as components: (1) A systematic review of publications about foods in which NTS, serotypes and AMR patterns have been reported in Latin America; (2) the determination of the ability of *Salmonella* to grow in fresh chicken faecal matter, to know its behavior once it is excreted from an animal host, which may have repercussions on food contamination; and (3) the isolation of bacteriophages from wastewater, and their application on a commercial poultry farm as part of a search strategy for antibiotic substitutes. From this work it can be concluded that, with the increase in large-scale food production, and due to the NTS ability to multiply in faeces outside the host, the use of manure as fertilizer without adequate treatment contributes to this pathogen contaminating produce. Given this risk, appropriate control actions are necessary to prevent NTS dissemination and entry into the food chain. On the other hand, based on the results obtained, it can be affirmed that bacteriophages constitute a viable alternative to replace antibiotics

against *Salmonella* in the poultry industry; however, it is necessary to monitor the spread of bacteriophage-resistant bacteria in the future.

Keywords: Nontyphoidal *Salmonella*, food, Latin America, chicken faecal matter, *Salmonella* bacteriophages, poultry farms.

TABLA DE CONTENIDO

ÍNDICE DE TABLAS

ÍNDICE DE FIGURAS

CHAPTER 1

Foodborne Pathogens and Disease. Published Online:19 Oct 2021.
https://doi.org/10.1089/fpd.2020.2925

Systematic review: Non-typhoidal *Salmonella* in food from Latin America

Teresa Guerrero[1]*, Rosa Bayas-Rea[1], Emilene Erazo[1], and Sonia Zapata Mena[1]*

[1] Instituto de Microbiología, Colegio de Ciencias Biológicas y Ambientales, Universidad San Francisco de Quito.

* Corresponding authors:

Teresa Guerrero. Universidad San Francisco de Quito, Diego de Robles y Vía Interoceánica, Cumbayá, Quito, Ecuador. E-mail: tguerrero@estud.usfq.edu.ec.

Sonia Zapata Mena. Universidad San Francisco de Quito, Diego de Robles y Vía Interoceánica, Cumbayá, Quito, Ecuador. E-mail: szapata@usfq.edu.ec

Abstract

In Latin America, nontyphoidal *Salmonella* (NTS) is one of the most important etiological agents of foodborne infections; it can survive in soil, water, and food even after processing. Here, we aimed to perform a systematic review by collecting data on the prevalence, serotypes, and antimicrobial resistance (AMR) of NTS isolated from different food products in Latin America, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Out of 1766 studies screened, 244 reports from 13 Latin American countries were eligible. Among these, 182 reported NTS prevalence, 87 reported NTS serotypes, and 83 reported serotypes with AMR patterns. The NTS prevalence ranged from 0.005% to 93.3%, regardless of country and food. Meat showed the highest NTS prevalence. Enteritidis, Typhimurium, and Derby were the most frequently observed serotypes in different food products. The serotypes Enteritidis, Typhimurium, and Infantis, isolated from animal products,

showed the highest AMR rate. The presence of NTS in fruits and vegetables, which are generally consumed raw or as ready-to-eat food, indicates a high risk of salmonellosis from consuming these foods. Thus, the reduction of this pathogen in the food chain requires a One Health approach, involving good agricultural and manufacturing practices, low antimicrobial use, and proper waste management.

Keywords: Non-typhoidal *Salmonella*, food, Latin America

Introduction

According to the Food and Agricultural Organization of the United Nations (FAO), Latin America produces enough food to feed its population (FAO, 2020a); this has resulted in the intensification of agriculture and commercial trade with consequential environmental deterioration (Kopittke *et al*., 2019; Kaimowitz, 2020). These conditions increase the prevalence of zoonotic foodborne pathogens in farm animals and crops (FAO, 2020a).

In low- and middle-income countries, including most Latin America countries, the use of wastewater for agricultural purposes and animal waste as fertilizers is not regulated (Khalid *et al*., 2018), which can lead to pathogen contamination of edible crops (Mandrell, 2009).

In Latin America, ~77 million people become ill and 9000 die annually owing to contaminated food. *Norovirus*, *Campylobacter*, *Escherichia coli*, and nontyphoidal *Salmonella* (NTS) account for 95% of food poisoning cases in the Region of the Americas (WHO, 2015). Foodborne illnesses result in financial losses for governments, producers, and consumers (FAO, 2020b). In addition, Latin America lacks funding for food safety research (Jaffee *et al*., 2019). These data highlight the need for improvement of national public policies regarding agriculture and food safety, as well as regional programs for the prevention, control, and eradication of pests and animal diseases (FAO, 2020a).

Salmonella is a ubiquitous bacterium that can survive for several weeks in soil, water, and food (WHO, 2018); it can also survive and multiply in fresh faecal matter (Guerrero et al., 2020). *Salmonella* can also grow on plants; therefore, fruits and vegetables may act as routes of *Salmonella* entry into the food chain (Silva *et al*., 2014). In animal products, NTS infection occurs through feed or environmental contamination (Hoelzer *et al*., 2011; WHO, 2018).

NTS is the leading bacterial cause of foodborne illnesses worldwide (CDC, 2020). Most nontyphoidal salmonellosis cases are mild; however, they may lead to life-threatening complications in children, the elderly, and people with disabilities. NTS infection severity depends on host immunity, *Salmonella* serotype, and infective dose. In addition, antimicrobial-resistant NTS serotypes have emerged, contributing to the global public health crisis (WHO, 2018), including NTS serotypes that are multidrug-resistant (MDR; resistant to ≥ 3 antimicrobial classes), third-generation cephalosporin resistant (3GCr), fluoroquinolone nonsusceptible (FQNS), and extended-spectrum beta-lactamase (ESBL) producers (WHO, 2017; McDermott *et al*., 2018; Tack *et al*., 2020).

Here, we aimed to perform a systematic review of publications selected based on defined inclusion criteria for the detection and prevalence of NTS serotypes in food from Latin American countries, as well as the evaluation of antimicrobial resistance (AMR) patterns of these serotypes.

Methods

Research strategy

We used the following inclusion criteria: 1) articles published in English, Portuguese, and Spanish; 2) primary research reports; 3) NTS isolated from food; and 4) food originating in Latin American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua,

Panama, Paraguay, Peru, Puerto Rico, Uruguay, or Venezuela). A systematic review was carried out in the following four steps: 1) bibliographic source identification, 2) record screening, 3) record eligibility, and 4) record inclusion (Moher *et al*., 2015; Cardona-Arias *et al*., 2016) (Fig. 1).

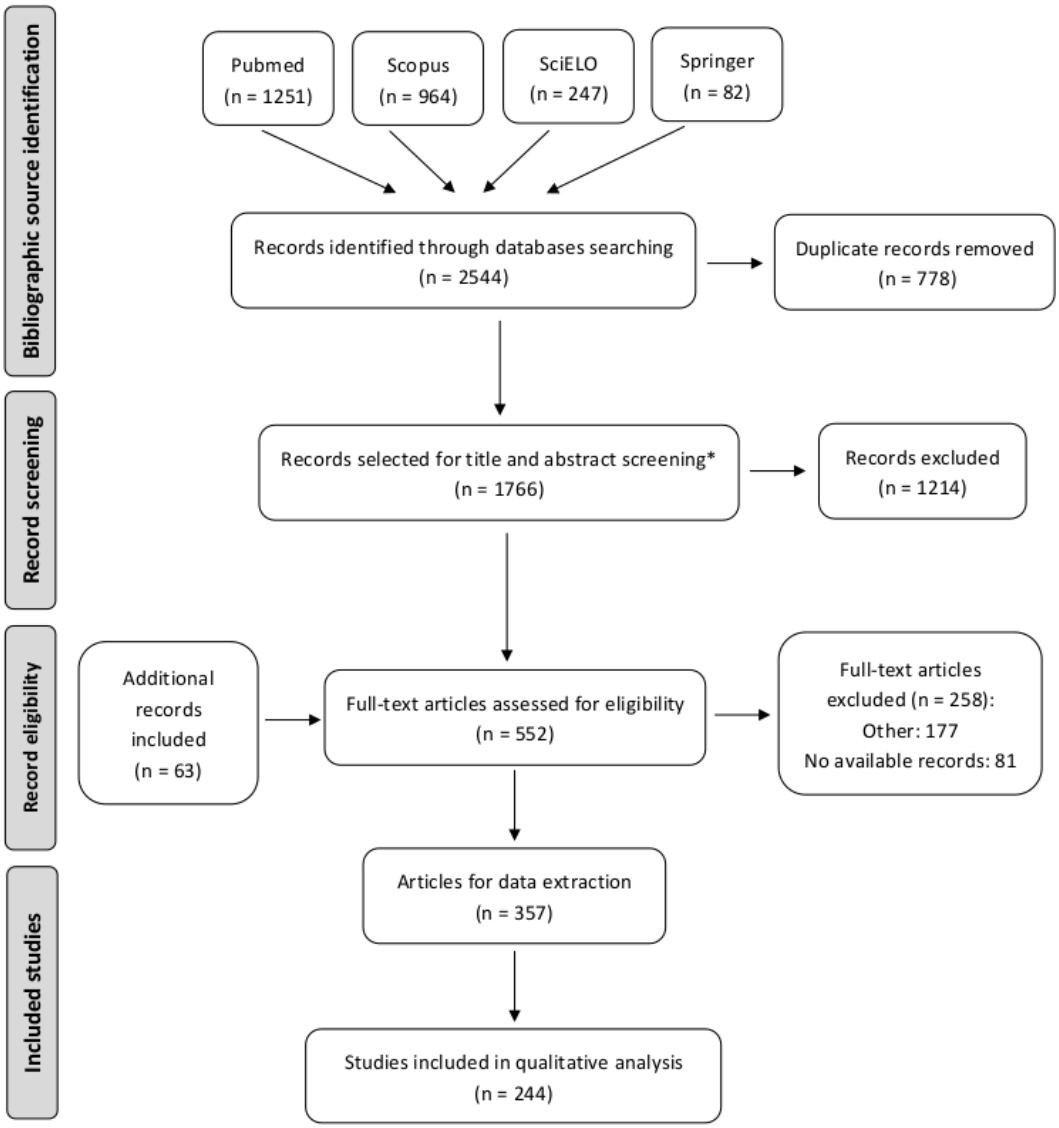


FIG. 1. PRISMA flow diagram of the literature search and data extraction. From Moher *et al*. (2009).

Bibliographic source identification

The electronic databases used were PubMed, Scopus, SciELO, and Springer. The following search terms were used: "*Salmonella*" AND ([food OR bread OR cooking OR drink OR feed OR foodstuff OR meal OR meat OR snack] AND [Argentina OR Bolivia OR Brazil OR Chile OR Colombia OR "Costa Rica" OR Cuba OR "Dominican Republic" OR Ecuador OR "El Salvador" OR Guatemala OR Haiti OR Honduras OR Mexico OR Nicaragua OR Panama OR Paraguay OR Peru OR "Puerto Rico" OR Uruguay OR Venezuela]). The last research data were obtained on July 19, 2020. No publication date restrictions were applied (Supplementary Table S1).

Record screening

In the first screening, T.G. removed duplicate records. To minimize bias, T.G. and R.B.-R. selected articles based on titles and abstracts according to the inclusion criteria. A third reviewer (S.Z.M.) resolved disagreements between the first two reviewers.

Record eligibility

The last screening and data extraction of all selected publications were performed by T.G., R.B.-R., and E.E. The following information was extracted: 1) country from which the food originated, 2) sampling date, 3) analyzed food, 4) NTS serotypes, 5) laboratory methods, 6) sample size, 7) prevalence, and 8) AMR of the isolates. We excluded studies on NTS from nonfood sources, that did not identify NTS using laboratory methods, that did not specify the food source of NTS, and in which the food's origin was not Latin American. The final review of the results and the approval of the article were carried out by S.Z.M.

Record inclusion

The qualitative analysis included previously chosen publications containing information on NTS prevalence, serotypes, and AMR and additional articles obtained through manual screening of the reference lists of the retrieved reviews, systematic reviews, and meta-analyses. For AMR reports we used four criteria: MDR, 3GCr, FQNS, and ESBL producers. In this

review, we reported the prevalence as described in the original studies, and the sample size, represented by *n*.

Results

Search results and study selection

We obtained 2544 records from the databases, which included 778 duplicate records. Ultimately, 1766 original records were available for further screening. After selection by titles and abstracts, 552 records were assessed for eligibility. Of these, 258 were excluded: 177 were removed based on the inclusion criteria, and 81 were removed owing to unavailability of full texts in the databases. We also included 63 records extracted from reviews, systematic reviews, and meta-analyses. Finally, we had a total of 357 records for data extraction; of these, 244 were included in the qualitative analysis (Fig. 1). These records were reported from 13 Latin American countries (Fig. 2).

FIG. 2. Number of articles from which the data were extracted, by country.

We classified the selected records based on country, NTS prevalence, serotypes, and AMR patterns. A total of 182 records from 13 countries reported NTS prevalence, 87 from 12 countries reported *Salmonella* serotypes, and 83 from 10 countries reported serotypes with AMR patterns (Fig. 2). In addition, we grouped the food into meat (chicken, bovine meat, pork), vegetables, fruits, dairy products, sausages, eggs, seafood, spices, animal feed, ready-to-eat (RTE), and other foods.

Reported prevalence of NTS in various food products

Mexico and Brazil had the largest number of food groups analyzed. The NTS prevalence ranged from 0.005% to 93.3%, regardless of country and food (Table 1). The highest NTS prevalence

was found in chicken, pork and bovine meat from Brazil, Colombia, Ecuador, Mexico, and Venezuela; the lowest prevalence was found in eggs from Chile and Uruguay. In particular, Venezuela, Ecuador and Colombia reported the highest NTS prevalence in chicken, whereas Brazil and Mexico in pork, and Ecuador and Brazil in bovine meat (60%–93.3%). In contrast, Paraguay showed the lowest prevalence in chicken, Argentina and Peru in pork, and Uruguay and Costa Rica in bovine meat (0.4%–7%).

A wide range of NTS prevalence (4.4%–88.3%) was found in sausages, with Mexican pork sausage having the highest contamination prevalence (*n*=200). In dairy products, the prevalence range was 0.4%–62.9%, with Colombian fresh cheese being the most frequently contaminated product (*n*=27). Vegetables, fruits, and their derivatives presented a prevalence range of 0.4%–40%. Farmed fish and seafood products showed a considerable range of NTS prevalence of 0.9%–50%, with Peruvian shrimp being the most contaminated (*n*=2).

The NTS prevalence range in animal feed was 1.3%–66.7% and that in animal feed raw materials was 0.5%–26.7%. Chocolate, peanuts, and RTE food showed the lowest contamination (< 5%).

Distribution and diversity of NTS serotypes in various food products

Overall, a total of 39 serotypes were reported in studies from the selected countries, with Brazil (22), Mexico (11), and Colombia (11) having the most available data. Some serotypes were present in only one country, such as Brazil (12), Colombia (6), Mexico (3), Costa Rica (1), Cuba (1), and Venezuela (1) (Table 2 Supplementary Table S2). The greatest diversity of serotypes in a wide variety of foods was detected in Brazil.

Enteritidis, Typhimurium, and Derby were the most frequent *Salmonella* serotypes in different food products of several countries. Here, Enteritidis was found mainly in chicken products, although it was also reported in vegetables, processed food, and chili sauce. Typhimurium was

present in both plant and animal products. Derby was found in pork products, chocolate, eggs, and RTE food.

The serotypes Infantis and Enteritidis were reported frequently in Chile and Ecuador, mostly in chicken products. Infantis was also reported in Brazilian pork and Cuban dairy products. The serotype Heidelberg was found at a low rate (< 40%) in chicken products from Brazil and Venezuela but predominated the feedstuff from Costa Rica (Fig. 3). Uganda was the most frequent serotype in Colombian meat, but it was not found in food products from other countries. The serotypes Rubislaw and Miami were reported only in drinking water and peanuts in Colombia and Brazil, respectively.

FIG. 3. Main nontyphoidal *Salmonella* serotypes and related food, by country.

The most common serotypes isolated from chicken were Enteritidis, Infantis, Albany, and Schwarzengrund in Chile, Brazil, and Ecuador; chicken giblets presented the serotypes Infantis, Typhimurium, Enteritidis, and Schwarzengrund in Ecuador, Mexico, Chile, and Argentina. Enteritidis and Senftenberg were found in eggs in Chile, Ecuador, Colombia, and Brazil. In

bovine meat, Newport and Livingstone were reported in Uruguay and Brazil, whereas in pork, Typhimurium, Derby, and Infantis were reported in Argentina, Peru, and Brazil (Fig. 3). A high frequency of Typhimurium (47%–100%) and a low frequency of the serotypes Bredeney, Derby, Anatum, and Saintpaul (< 34%) were found in Brazilian pork sausages. In Mexico, the serotypes Typhimurium and Enteritidis were detected in vegetables, and Typhimurium and Agona were found in fruits. Typhimurium, Enteritidis, Agona, and Anatum were found in Mexican fruit juices, and Choleraesuis was reported in Brazilian orange juice. In Brazilian seafood, the frequency of the serotypes Senftenberg and Panama was high (> 70%) whereas that of Tennessee and Poona was low (< 28%). Finally, the serotypes Havana, Heidelberg, and Infantis were common in animal feed from Costa Rica and Ecuador, whereas Senftenberg was detected in low percentages in animal feed from Brazil.

AMR of NTS in various food products

We found 83 publications with AMR patterns of more than 5500 NTS isolates belonging to 75 serotypes. For the AMR analysis, we only considered 66 publications containing the sampling date of the tested food (from 1975 to 2017) (Supplementary Table S3).

The most frequent resistance was to tetracycline, ampicillin, streptomycin, nalidixic acid, sulfamethoxazole-trimethoprim, chloramphenicol, and gentamicin. Resistance to tetracycline, ampicillin, streptomycin, and gentamicin has been reported since 1975, whereas that to nalidixic acid, sulfamethoxazole-trimethoprim, and chloramphenicol has only been reported since 1995. The first reports of 3GCr (cefotaxime and ceftriaxone) and FQNS (norfloxacin) were for isolates from poultry meat and giblets in Brazil in 1995.

The most common antimicrobial-resistant NTS serotypes were Typhimurium, Enteritidis and Infantis. MDR-3GCr Typhimurium strains were found in pork and poultry from Brazil, Colombia, and Mexico, whereas MDR-FQNS and MDR-3GCr-FQNS strains were predominantly in pork from Brazil, Ecuador, and Mexico. MDR, MDR-FQNS, and MDR-

3GCr-FQNS Enteritidis isolates were found in poultry, eggs, egg-meals, and poultry products from Argentina, Brazil, and Venezuela. MDR Infantis strains were isolated from pork, poultry, and beef; MDR-3GCr, MDR-FQNS, and MDR-3GCr-FQNS strains were present in pork and poultry from Brazil, Colombia, Ecuador, and Mexico. The most frequent ESBL producers were Heidelberg and Typhimurium, isolated from chicken and turkey in Brazil and Venezuela, with the first report from the year 2000.

Discussion

Foodborne diseases caused by NTS are a global public concern, which becomes more acute with the increase in AMR among foodborne NTS isolates. Our findings reveal important data on the prevalence of NTS and the diversity of antimicrobial-resistant NTS serotypes.

NTS prevalence was over 70% in some raw animal products (pork, beef, and chicken). This is comparable with that reported by Contreras-Soto *et al*., thus suggesting that, although *Salmonella* can survive in soil and water, most food contamination with NTS originates from animal sources. Healthy animals can carry NTS, and their carcasses become contaminated with gastrointestinal content during slaughter (Gómez-Aldapa *et al*., 2012; Contreras-Soto *et al*., 2019). In Mexico, the skin and lymph nodes have been identified as potential sources of NTS contamination of bovine meat (Gragg *et al*., 2013), whereas in Brazil, the presence of NTS in pork has been associated with residual environmental contamination and contaminated feed (Tondo and Ritter, 2012).

Most dairy-borne *Salmonella* infections have been associated with raw or improperly pasteurized milk or post-pasteurization contamination *(*El-Gazzar and Marth, 1992). We identified fresh Colombian cheese as a source of *Salmonella*, suggesting deficiencies in processing, transportation, storage, and/or retail marketing (de Souza *et al*., 2017).

The low prevalence of NTS among eggs in Uruguay could be due to factors, such as vaccination against *Salmonella* in laying hens, type of housing system, cleaning and disinfection protocols in farms, water sanitation, and feed safety. Anti-NTS vaccination is a control measure, but its effectiveness decreases if bird environments contain high bacterial loads (Betancor *et al*., 2010; Terzolo, 2010).

NTS in edible vegetables, such as Brazilian collard greens or Mexican melons, has been associated with the use of manure (mainly from pigs or poultry) for fertilization and contaminated water for irrigation, and the lack of hygiene protocols for workers handling products (ICMSF, 1980; Espinoza-Medina *et al*., 2006; Gallegos-Robles *et al*., 2008; Morales-Hernández *et al*., 2009; Jechalke *et al*., 2019). Such contaminated food contributes to an increasing risk of salmonellosis because it is generally consumed raw. In addition, if *Salmonella* is not controlled early, it can penetrate plant tissues, and subsequent disinfection treatments may be ineffective (Quiroz-Santiago *et al*., 2009; Freitas *et al*., 2010; da Cruz *et al*., 2019).

The prevalence of NTS in RTE food (egg arepa, rice, chicken, corn tortilla, and beef enchilada) and drinking water is low, but could still be risky because they are not often subjected to sanitation processes before ingestion. NTS has an infectious dose as low as 10 cells, depending on the ingested food (Finn *et al*., 2013). The lack of knowledge and hygiene standards in the processing and sale of street food, common in Latin American countries, can also increase the presence of pathogens, such as *Salmonella* (Valadez *et al*., 2017).

In our study, the most prevalent serotypes were Enteritidis, Typhimurium and Derby. Enteritidis and Typhimurium were found mainly in chicken and pork respectively, suggesting that these animals constitute their potential reservoirs; these serotypes are associated with a high burden of foodborne *Salmonella* outbreaks in humans (Godínez-Oviedo *et al*., 2019; Jajere, 2019; Mechesso *et al*., 2020). Derby has been reported in pork production in Asia, North America, and Europe (Sanchez-Maldonado *et al*., 2017; Bonardi *et al*., 2019; Xu *et al*., 2019); however,

its relationship with human diseases is not fully understood. The high prevalence of Derby in pork products is owing to pigs being the main reservoir of this serotype, and therefore, comprehensive surveillance is needed for its control (Ferrari *et al*., 2019).

Studies from Chile and Ecuador reported that Infantis is predominant in chicken, suggesting that this serotype is becoming more prevalent than Enteritidis in chicken farming, probably owing to control measures against Enteritidis (Lapierre *et al*., 2020). In Argentina and Brazil, the predominant serotype was Enteritidis, although the presence of Infantis was also noted in Brazil (Voss-Rech *et al*., 2015). In Argentina, Infantis was the second most common serotype, isolated also from hospitalized pediatric patients (Merino *et al*., 2003), which may be a result of its high prevalence in food.

Although sausages undergo preservation processes, NTS has also been reported in this food, suggesting production failures or cross contamination (Escartin *et al*., 1999). The most frequent serotype found in Brazilian pork sausages was Typhimurium; the source of the pathogen may be animal ingredients because Typhimurium was frequently observed in pork cuts, but it could also be from other ingredients, such as spices (Costa *et al*., 2020).

Another concern regarding the ubiquity of NTS (food, humans, animals, and the environment) is its AMR, which arises because of the use of antimicrobials in animal husbandry (Silva *et al*., 2014; McDermott *et al*., 2018). We found that Typhimurium, Enteritidis and Infantis were the most commonly reported antimicrobial-resistant NTS serotypes, including MDR, 3GCr, and FQNS isolates. These clinically important antimicrobials are used to treat invasive NTS infections (Mechesso *et al*., 2020).

Our systematic review had some limitations, such as the following. 1) In most studies, the sample size was not statistically calculated, which could have introduced a statistical bias; and 2) some publications were excluded owing to incomplete published data (missing sampling date of the food or unspecified analyzed food).

Conclusions

Through this systematic review of Latin American publications, we showed that, although there is an increasing number of NTS isolated from fruits and vegetables, animal products are the most common carriers of NTS and MDR NTS. Our data correspond with the notion that the current global health problem of AMR is partially related to antimicrobial use in animal husbandry. Therefore, it is critical for Latin America to implement good agricultural practices, reduce the use of antimicrobials in animal husbandry, and implement proper waste management regulations. In addition, an integrated epidemiological surveillance system with the participation of both governmental and non-governmental institutions that handle data regarding food and clinical samples will improve food safety programs.

Acknowledgments

We are grateful to Gabriel Trueba for reviewing the final version of this article. We also thank Verónica Barragán, Daniel Marín, and Andrés Suárez for their collaboration during the development of this systematic review.

Disclosure Statement

No competing financial interests exist.

Funding Information

Publication of this article was funded by the Universidad San Francisco de Quito USFQ Postgraduate Funds.

References

Abrantes M, Sousa AC, Araújo N de, Sousa Ê de, Oliveira A de, Silva J da. Avaliação microbiológica de carne de charque produzida industrialmente. Arq Inst Biol 2014;81(3):282–285.

Albuquerque R, Ito N, Miyaji C. Estudo da ocorrência de salmonelas em ingredientes, rações e suabes de pó colhidos em uma fábrica industrial de ração. Braz J Vet Res Anim Sci 1999;36(6):324–326.

Alexandre M, Pozo C, González V, Martínez MC, Prat S, Fernández A, Fica A, Fernández J, Heitmann I. Detection of *Salmonella* enteritidis in samples of poultry products for human consumption in the Chilean Metropolitan Area. Rev Méd Chile 2000;128(10):1075–1083.

Arias ML, Utzinger D, Antillón F, Glenn E. Natural presence of the bacterium *Salmonella* sp. in hen eggs consumed in Costa Rica. Rev Biol Trop 1996;44(2):891–893.

Asensi GF, Reis EM dos, Del Aguila EM, Rodrigues D, Silva JT, Paschoalin VM. Detection of *Escherichia coli* and *Salmonella* in chicken rinse carcasses. Br Food J 2009;111(6):517–527.

Avila-Vega DE, Álvarez-Mayorga B, Arvizu-Medrano SM, Pacheco-Aguilar R, Martínez-Peniche R, Hernández-Iturriaga M. Microbiological profile and incidence of *Salmonella* and *Listeria monocytogenes* on hydroponic bell peppers and greenhouse cultivation environment. J Food Prot 2014;77(11):1904–1910.

Baptista D, Santos A, Aquino MH, Abreu D, Rodrigues D, Nascimento E, Pereira V. Prevalência e susceptibilidade antimicrobiana de sorotipos de *Salmonella* spp. isolados de frangos vivos e carcaças no estado do Rio de Janeiro. Pesq Vet Bras 2018;38(7):1278–1285.

Barril PA, Soto SA, Jaureguiberry MV, Gottardi G, Bascur I, Leotta GA, Oteiza JM. Microbiological risk characterization in butcher shops from the province of Neuquen, Patagonia Argentina. LWT - Food Sci Technol 2019;107:35–40.

Baú AC, Carvalhal JB, Aleixo JA. Prevalência de *Salmonella* em produtos de frangos e ovos de galinha comercializados em Pelotas, Rs, Brasil. Ciência Rural 2001;31(2):303–307.

Becerril AL, Dublán O, Domínguez-López A, Arizmendi D, Quintero-Salazar B. Hygienic quality of the traditional red chorizo commercialized in the city of Toluca, State of Mexico. Rev Mex Cienc Pecu 2019;10(1):172– 185.

Bello-Pérez LA, Ortiz-Dillanes DM, Pérez-Memije E, Castro-Domínguez V. *Salmonella* en carnes crudas: un estudio en localidades del estado de Guerrero. Salud Publ Mex 1990;32(1):74–79.

Beltrão J, Pereira L, Gonzalez A. (2017). Microbiological analysis and evaluation of Good Manufacturing Practices during the processing of raw white cabbage (*Brassica oleracea* var. *capitata* f. alba) served in a self-service restaurant. Vigil sanit debate 2017;5(4):1-8.

Benetti TM, Monteiro CL, Beux MR, Abrahão WM. (2013). Enzyme-linked immunoassays for the detection of *Listeria* sp. and *Salmonella* sp. in sausage: A comparison with conventional methods. Braz J Microbiol 2013;44(3):791–794.

Bersot L, Viana C, Sereno M, Perin AP, Barcellos V. Occurrence of *Salmonella* sp. In poultry

carcasses evaluated from the retail trade between 2007 and 2013 in Paraná State, Brazil. Braz J Vet Res An Sci 2019;56(2):1-7.

Bersot L, Cavicchioli V, Viana C, Burin RC, Camargo AC, Almeida J, Nero LA, Destro MT. Prevalence, antimicrobial resistance, and diversity of *Salmonella* along the pig production chain in Southern Brazil. Pathogens 2019;8(204):1–10.

Betancor L, Pereira M, Martinez A, Giossa G, Fookes M, Flores K, Barrios P, Repiso V, Vignoli R, Cordeiro N, Algorta G, Thomson N, Maskell D, Schelotto F, Chabalgoity JA. Prevalence of *Salmonella enterica* in poultry and eggs in Uruguay during an epidemic due to *Salmonella enterica* serovar Enteritidis. J Clin Microbiol 2010;48(7):2413–2423.

Bier D, Kich JD, Duarte SC, Silva MR, Valsoni LM, Ramos CA, Rodrigues DP, Araújo F. Survey of *Salmonella* spp. in beef meat for export at slaughterhouses in Brazil. Pesq Vet Bras 2018;38(11):2037–2043.

Bonardi S, Bolzoni L, Zanoni RG, Morganti M, Corradi M, Gilioli S, Pongolini S. Limited exchange of *Salmonella* among domestic pigs and wild boars in Italy. EcoHealth 2019;16(3):420–428.

Borowsky LM, Schmidt V, Cardoso M. Estimation of most probable number of *Salmonella* in minced pork samples. Braz J Microbiol 2007;38(3):544–546.

Boscán LA, Arzálluz AM, Ugarte CI, Sánchez D, Díaz D, Wittum TE, Hoet AE. Isolation of *Salmonella*s with zoonotic importance in viscera from broiler chickens in Zulia State, Venezuela. Revista Científica FCV-LUZ 2005;15(6):576–582.

Boscán-Duque LA, Arzálluz-Fisher AM, Ugarte C, Sánchez D, Wittum TE, Hoet AE. Reduced susceptibility to quinolones among *Salmonella* serotypes isolated from poultry at slaughter in Venezuela. J Food Prot 2007;70(9):2030-2035.

Bosilevac JM, Guerini MN, Brichta-Harhay DM, Arthur TM, Koohmaraie M. Microbiological characterization of imported and domestic boneless beef trim used for ground beef. J Food Prot 2007;70(2):440–449.

Cabral C, Conte-Junior C, Silva J, Paschoalin V. *Salmonella* spp. contamination in fresh pork and chicken sausages marketed in Niterói and Rio de Janeiro, Brazil. J Verbrauch Lebensm 2014;9(3):243–249.

Cabral C, Panzenhagen PH, Delgado K, Silva G, Rodrigues D, Franco R, Conte-Junior C. Contamination of carcasses and utensils in small swine slaughterhouses by *Salmonella* in the northwestern region of the state of Rio de Janeiro, Brazil. J Food Prot 2017;80(7):1128–1132.

Cabrera-Diaz E, Barbosa-Cardenas CM, Perez-Montaño JA, Gonzalez-Aguilar D, Pacheco-Gallardo C, Barba J. Occurrence, serotype diversity, and antimicrobial resistance of *Salmonella* in ground beef at retail stores in Jalisco State, Mexico. J Food Prot 2013;76(12):2004–2010.

Campoverde AD. Microbiological evaluation of *Escherichia coli* and *Salmonella* in artisanal sausages (chorizo and blood sausage) sold in the markets of the city of Tulcán

[Evaluación microbiológica de *Escherichia coli* y *Salmonella* en embutidos artesanales (chorizo y morcilla) expendidos en los mercados de la ciudad de Tulcán]. Universidad Politécnica Estatal del Carchi, 2015. Available at: http://repositorio.upec.edu.ec/handle/123456789/357, accessed July 9, 2021.

Cardona-Arias JA, Higuita-Gutiérrez LF, Ríos LA. Performance of systematic reviews and meta-analysis, In: *Revisiones sistemáticas de la literatura científica: la investigación teórica como principio para el desarrollo de la ciencia básica y aplicada*. Acero M, Cuasialpud R, Cuéllar C, Urquijo D, eds. Bogotá: Ediciones Universidad Cooperativa de Colombia, 2016, pp. 25–40.

Carvalho AC, Cortez AL. *Salmonella* spp. em carcaças, carne mecanicamente separada, lingüiças e cortes comerciais de frango. Ciência Rural 2005;35(6):1465–1468.

Carvalho SV, Rogovski P, Cadamuro R, Viancelli A, Michelon W, Reis D dos, Chagas I das, Assenço R, Lanna MC, Treichel H, Fongaro G. Co-contamination of food products from family farms in an environmental disaster area in Southeast Brazil with pathogenic bacteria and enteric viruses. Arch Virol 2019;165(3)715–718.

Castagna SM, Muller M, Macagnan M, Rodenbusch CR, Canal C, Cardoso M. Detection of *Salmonella* sp. from porcine origin: A comparison between a PCR method and standard microbiological techniques. Braz J Microbiol 2005;36:373–377.

Castañeda-Ramírez C, Cortes-Rodríguez V, Fuente-Salcido N de la, Bideshi DK, Rincón-Castro MC del, Barboza-Corona JE. Isolation of *Salmonella* spp. from lettuce and evaluation of its susceptibility to novel bacteriocins of *Bacillus thuringiensis* and antibiotics. J Food Prot 2011;74(2):274–278.

Castillo A, Villarruel-López A, Navarro-Hidalgo V, Martínez-González NE, Torres-Vitela MR. *Salmonella* and *Shigella* in freshly squeezed orange juice, fresh oranges, and wiping cloths collected from public markets and street booths in Guadalajara, Mexico: Incidence and comparison of analytical routes. J Food Prot 2006;69(11):2595–2599.

Castro-Rosas *J, Gómez-Aldapa CA, Acevedo-Sandoval OA, González CA, Villagomez-Ibarra JR, Chavarría N, Villarruel-López A, Torres-Vitela MR. Frequency and behavior of Salmonella and* Escherichia coli *on whole and sliced jalapeño and serrano peppers. J Food Prot 2011;74(6):874–881.*

Castro-Rosas J, Santos EM, Gómez-Aldapa CA, González CA, Villagomez-Ibarra JR, Gordillo-Martínez AJ, Villarruel A, Torres-Vitela MR. Incidence and behavior of *Salmonella* and *Escherichia* coli on whole and sliced zucchini squash (*Cucurbita pepo*) fruit. J Food Prot 2010;73(8):1423–1429.

Cavalin PB, Sarmiento JJ, Kobayashi RK, Nakazato G, Ocaña A, Oliveira TC. Detection of *Salmonella* spp. and diarrheagenic *Escherichia coli* in fresh pork sausages. Semin Cienc Agrar 2018;39(4):1533–1545.

CDC. (2020). Foodborne Germs and Illnesses. Retrieved August 27, 2020, from https://www.cdc.gov/foodsafety/foodborne-germs.html

Chaves BD and Brashears MM. Prevalence of molecular markers for *Salmonella* and Shiga toxigenic *Escherichia coli* (STEC) in whole-muscle beef cuts sold at retail markets in Costa Rica. Food Control 2014;50:497-501.

Chávez-Martínez A, Paredes-Montoya P, Rentería-Monterrubio AL, Corral-Luna A, Lechuga-Valles R, Dominguez-Viveros J, Sánchez-Vega R, Santellano-Estrada E. Microbial quality and prevalence of foodborne pathogens of cheeses commercialized at different retail points in Mexico. Food Sci Technol 2019;39:703–710.

Colello R, Ruiz MJ, Padin VM, Rogé AD, Leotta G, Padola NL, Etcheverría AI. (2018). Detection and characterization of *Salmonella* serotypes in the production chain of two pig farms in Buenos Aires Province, Argentina. Front Microbiol 2018;9,1370.

Contreras-Soto MB, Medrano-Félix JA, Ibarra-Rodríguez JR, Martínez-Urtaza J, Chaidez QC, Castro-del Campo N. The last 50 years of *Salmonella* in Mexico: Sources of isolation and factors that influence its prevalence and diversity. Revista Bio Ciencias 2019;6(2):1–26.

Corbellini LG, Júnior A, Costa E, Duarte AS, Albuquerque E, Kich J, Cardoso M, Nauta M. Effect of slaughterhouse and day of sample on the probability of a pig carcass being *Salmonella*-positive according to the *Enterobacteriaceae* count in the largest Brazilian pork production region. Int J Food Microbiol 2016;228:58–66.

Cortez AL, Carvalho AC de, Ikuno AA, Bürger KP, Vidal-Martins AM. (2006). Resistência antimicrobiana de cepas de *Salmonella* spp. isoladas de abatedouros de aves. Arq Inst Biol São Paulo 2006;73(2):157–163.

Cossi MV, Almeida M de, Dias M, Pinto PS, Nero LA. Inspected and non-inspected chilled chicken carcasses commercialized in Viçosa, MG, Brazil: microbiological parameters and *Salmonella* spp. occurrence. Ciência Rural 2012;42(9):1675–1681.

Cossi MV, Burin RC, Camargo AC, Dias M, Lanna FG, Pinto PS, Nero LA. Low occurrence of *Salmonella* in the beef processing chain from Minas Gerais state, Brazil: From bovine hides to end cuts. Food Control 2014;40(1):320–323.

Costa M, Cruz AI, Bispo AS, Ferreira M, Costa J, Evangelista-Barreto NS. Occurrence and antimicrobial resistance of bacteria in retail market spices. Ciencia Rural 2020;50(4):1–7.

Cruz M da, Leite YJ, Marques J, Pavelquesi SL, Oliveira L, Silva IC da, Orsi D. Microbiological quality of minimally processed vegetables commercialized in Brasilia, DF, Brazil. Food Sci Technol 2019;39:1-6.

Cunha-Neto A da, Carvalho L, Carvalho RC, Rodrigues D, Mano S, Figueiredo EE, Conte-Junior C. *Salmonella* isolated from chicken carcasses from a slaughterhouse in the state of Mato Grosso, Brazil: antibiotic resistance profile, serotyping, and characterization by repetitive sequence-based PCR system. Poult Sci 2018;97(4):1373–1381.

Curi de Montbrun S, Blythman HE, Giménez DF. *Salmonella* en bovinos faenados. Boletìn de La Oficina Sanitaria Panamericana 1972:50–57.

Dias M, Cavicchioli V, Camargo AC, Lanna FG, Pinto PS, Bersot L, Nero LA. Molecular tracking of *Salmonella* spp. in chicken meat chain: from slaughterhouse reception to end cuts. J. Food Sci. Technol 2016;53(2):1084–1091.

Donado-Godoy P, Byrne BA, León M, Castellanos R, Vanegas C, Coral A, Arevalo A, Clavijo V, Vargas M, Romero JJ, Tafur MA, Pérez-Gutierrez E, Smith W. Prevalence, resistance patterns, and risk factors for antimicrobial resistance in bacteria from retail chicken meat in Colombia. J Food Prot 2015;78(4):751–759.

Donado-Godoy P, Clavijo V, León M, Tafur MA, Gonzales S, Hume M, Alali W, Walls I, Lo Fo Wong DM, Doyle MP. Prevalence of *Salmonella* on retail broiler chicken meat carcasses in Colombia. J Food Prot 2012;75(6):1134-1138.

El-Gazzar FE, Marth EH. (1992). *Salmonella*e, salmonellosis, and dairy foods: A review. J Dairy Sci 1992;75(9):2327–2343.

Escartin EF, Castillo A, Hinojosa-Puga A, Saldaña-Lozano J. Prevalence of *Salmonella* in chorizo and its survival under different storage temperatures. Food Microbiol 1999;16(5):479–486.

Espinal P, Prieto E, Otero V, Máttar S. Presencia del gen de invasividad *inv* A en cepas de *Salmonella* spp. aisladas de alimentos del Caribe Colombiano. Rev Cub Salud Pública 2006;32(2)115-120.

Espinoza-Medina IE, Rodríguez-Leyva FJ, Vargas-Arispuro I, Islas-Osuna MA, Acedo-Félix E, Martínez-Téllez MA. PCR identification of *Salmonella*: Potential contamination sources from production and postharvest handling of cantaloupes. J Food Prot 2006;69(6):1422–1425.

Estrada-Garcia T, Lopez-Saucedo C, Zamarripa-Ayala B, Thompson MR, Gutierrez-Cogco L, Mancera-Martinez A, Escobar-Gutierrez A. Prevalence of *Escherichia coli* and *Salmonella* spp. in street-vended food of open markets (tianguis) and general hygienic and trading practices in Mexico City. Epidemiol Infect 2004;132(6):1181–1184.

Evêncio-Luz L, Lima-Filho JV, Evêncio-Neto J. Occurrence of *Salmonella* sp. and coagulase-positive staphylococci in raw eggs and coalho cheese: Comparative study between two cities of Brazil's Northeast. Braz J Microbiol 2012;43(4):1463–1466.

Fai AE, de Figueiredo EA, Verdin SE, Pinheiro NM, Braga AR, Stamford TL. *Salmonella* sp. e *Listeria monocytogenes* em presunto suíno comercializado em supermercados de Fortaleza (CE, Brasil): fator de risco para a saúde pública. Cien Saude Colet 2011;16(2):657–662.

FAO. Food and nutrition security in Latin America and the Caribbean. FAO Regional Office for Latin America and the Caribbean. Food and Agriculture Organization of the United Nations. 2020a. Available at: http://www.fao.org/americas/prioridades/seguridad-alimentaria/en/, accessed August 27, 2020.

FAO. Food safety and animal and plant health in Latin America and the Caribbean. FAO Regional Office for Latin America and the Caribbean j Food and Agriculture Organization of the United Nations. 2020b. Available at:

http://www.fao.org/americas/prioridades/sanidad-inocuidad-agroalimentaria/en/, accessed August 27, 2020.

Favier GI, Lucero CSM, Lazarte V, Escudero ME. Prevalence, antimicrobial susceptibility, and molecular characterization by PCR and pulsed field gel electrophoresis (PFGE) of *Salmonella* spp. isolated from foods of animal origin in San Luis, Argentina. Food Control 2013;29(1):49–54.

Fernandes EF, Paulino AA, Fernandes MF, Moura AP, Mota RA. Qualidade microbiológica da carne de ovinos (*Ovis aries*) comercializada nos mercados públicos do Recife-PE. Med Vet 2009;3(4):7–12.

Ferrari RG, Rosario DK, Cunha-Neto A, Mano SB, Figueiredo EE, Conte-Junior CA. (2019). Worldwide epidemiology of *Salmonella* serovars in animal-based foods: A meta-analysis. Appl Environ Microbiol 2019;85(14):1–21.

Ferreira LC, Junqueira RG. Microbiological evaluation of pequi (*Caryocar brasiliense* Camb.) preserves made from a typical Brazilian fruit. World J Microbiol Biotechnol 2007;23:1179–1181.

Finn S, Condell O, McClure P, Amézquita A, Fanning S. Mechanisms of survival, responses, and sources of *Salmonella* in low-moisture environments. Front Microbiol 2013;4:1–15.

Forero Y, Galindo M, Ramírez G. Patógenos asociados a enfermedades transmitidas por alimentos en restaurantes escolares de Colombia. Rev Chil Nutr 2017;44(4):325-332

Freire BC, Melo EC de, Araújo N de, Rabelo JL, Soares KM. Microbiological characterization of vacuum-packed and conventionally packed sliced turkey hams marketed in Mossoró, Brazil. Acta Vet Bras 2019;13(1):30–36.

Freitas OC de, Galdino VM, Campello PL, Almeida AM de, Fernandes SA, Berchieri Junior A. *Salmonella* serovars in laying hen flocks and commercial table eggs from a region of São Paulo State, Brazil. R Bras Ci Avíc 2014;16(2):57–62.

Freitas OC de, Penha RA, Barrow P, Berchieri A. (2010). Sources of human non-typhoid salmonellosis: A review. R Bras Ci Avíc 2010;12(1):1–11.

Fröder H, Martins CG, de Souza K, Landgraf M, Franco B, Destro MT. (2007). Minimally processed vegetable salads: Microbial quality evaluation. J Food Prot 2007;70(5):1277-1280.

Gallegos-Robles MA, Morales-Loredo A, Alvarez-Ojeda G, Vega-P A, Chew-M Y, Velarde S, Fratamico P. Identification of *Salmonella* serotypes isolated from cantaloupe and chile pepper production systems in Mexico by PCR-restriction fragment length polymorphism. J Food Prot 2008;71(11):2217–2222.

Galvão J, Biondo A, Possebon F, Spina TL, Correia L, Zuim C, Filho J, Pantoja C, Almeida Nogueira J de. Microbiological vulnerability of eggs and environmental conditions in conventional and free-range housing syst*e*ms. Semin Cienc Agrar 2018;39(1):133–142.

Gecan JS, Bandler R, Staruszkiewicz WF. Fresh and frozen shrimp: A profile of filth, microbiological contamination, and decomposition. J Food Prot 1994;57(2):154–158.

Godínez-Oviedo A, Tamplin ML, Bowman JL, Hernández-Iturriaga M. *Salmonella enterica* in Mexico 2000-2017: Epidemiology, antimicrobial resistance, and prevalence in food. Foodborne Path Dis 2019;17(2):98–118.

Gómez-Aldapa CA, Gutiérrez-Alcántara EJ, Torres-Vitela MR, Rangel-Vargas E, Villarruel-López A, Castro-Rosas J. Prevalence and behavior of multidrug-resistant *Salmonella* strains on raw whole and cut nopalitos (*Opuntia ficus-indica* L.) and on nopalitos salads. J Sci Food Agric 2017;97(12):4117–4123.

Gómez-Aldapa CA, Rangel-Vargas E, Bautista-De León H, Castro-Rosas J. Presence of non-O157 Shiga toxin-producing *Escherichia coli*, enterotoxigenic *E. coli*, enteropathogenic *E. coli* and *Salmonella* in fresh beetroot (*Beta vulgaris* L.) juice from public markets in Mexico. J Sci Food Agric 2014;94(13):2705–2711.

Gómez-Aldapa CA, Rangel-Vargas E, Castro-Rosas J. Frequency and correlation of some enteric indicator bacteria and *Salmonella* in ready-to-eat raw vegetable salads from Mexican restaurants. J Food Sci 2013a;78(8):1201–1207.

Gómez-Aldapa CA, Rangel-Vargas E, Cruz AM, Román-Gutiérrez AD, Castro-Rosas J. (2013). Presence of coliform bacteria, faecal coliforms, *Escherichia coli* and *Salmonella* on corn tortillas in central Mexico. Food Control 2013b;32(1):31–34.

Gómez-Aldapa CA, Torres-Vitela MR, Villarruel-López A, Castro-Rosas J. The Role of Foods in *Salmonella* Infections, In: *Salmonella - A dangerous foodborne pathogen*. Mahmoud BS, ed. Croatia: InTech, 2012, pp. 21–46.

Gómez-Gamboa L, Bermúdez-González J, Medina Z, López M, Navarro J, Morales E. Diversidad de serotipos de *Salmonella* en camarones de cultivo crudos congelados (*Litopeneaus vannamei*) de Venezuela. Rev Soc Ven Microbiol 2012;32(1):22–28.

Gragg SE, Loneragan GH, Nightingale KK, Brichta-Harhay DM, Ruiz H, Elder JR, Garcia LG, Miller MF, Echeverry A, Ramírez RG, Brashears MM. Substantial within-animal diversity of *Salmonella* isolates from lymph nodes, feces, and hides of cattle at slaughter. Appl Environ Microbiol 2013;79(15):4744–4750.

Guerrero T, Calderón D, Zapata S, Trueba G. *Salmonella* grows massively and aerobically in chicken faecal matter. Microb Biotechnol 2020;13(5):1678–1684.

Gutiérrez-Alcántara EJ, Gómez-Aldapa CA, Román-Gutiérrez AD, Rangel-Vargas E, González-Olivares LG, Castro-Rosas J. Antimicrobial activity of roselle *Hibiscus Sabdariffa* calyx extracts on culture media and carrots against multidrug-resistant *Salmonella* strains isolated from raw carrots. J Food Saf 2016;36(4):450–458.

Guzmán-Gómez G, Ayala MA, Cabrera-Díaz E, Pérez-Montaño JA, Muñoz-Valle JF, Torres-Vitela MR, Ruiz-Quezada SL. Frequency of *Salmonella* and *Listeria monocytogenes* in five commercial brands of chicken eggs using a combined method of enrichment and nested-PCR. J Food Prot 2013;76(3):429–434.

Guzman-Hernandez R, Contreras-Rodriguez A, Hernandez-Velez R, Perez-Martinez I, Lopez-Merino A, Zaidi MB, Estrada-Garcia T. Mexican unpasteurised fresh cheeses are contaminated with *Salmonella* spp., non-O157 Shiga toxin producing *Escherichia coli* and potential uropathogenic *E. coli* strains: A public health risk. Int J Food Microbiol 2016;237:10–16.

Harvey RW, Price TH. A survey of Argentine and Lebanese bone for *Salmonella*s with particular reference to the isolation of *Salmonella typhimurium*. J Appl Bacteriol 1978;44(2):241–247.

Heredia N, García S, Rojas G, Salazar L. Microbiological condition of ground meat retailed in Monterrey, Mexico. J Food Prot 2001;64(8):1249–1251.

Hernandez T, Sierra A, Rodriguez-Alvarez C, Torres A, Arevalo MP, Calvo M, Arias A. *Salmonella enterica* serotypes isolated from imported frozen chicken meat in the Canary Islands. J Food Prot 2005;68(12):2702–2706.

Hoelzer K, Moreno AI, Wiedmann M. (2011). Animal contact as a source of human non-typhoidal salmonellosis. Vet Res 2011;42(34):1–27.

Hofer E, Zamora MR, Lopes AE, Moura AM de, Araújo H de, Leite J, Leite MD, da Silva Filho S. Sorovares de *Salmonella* em carne de eqüídeos abatidos no nordeste do Brasil. Pesq Vet Bras 2000;20(2):80–84.

ICMSF, The International Commission on Microbiological Specifications for Foods. 14 – Cleaning, Desinfection, and Hygiene, In: *Microbial ecology of foods: Volume 1 Factors affecting life and death of microorganisms*. Silliker JH, Elliott RP, Baird-Parker AC, Bryan FL, Christian JH, Clark DS, Olson JC, Roberts, T. A, eds. New York: Academic Press. Inc., 1980, pp. 232–258.

Jaffee S, Henson S, Unnevehr L, Grace D, Cassou E. *The Safe Food Imperative*. Washington, DC: The World Bank, 2019.

Jajere SM. A review of *Salmonella enterica* with particular focus on the pathogenicity and virulence factors, host specificity and antimicrobial resistance including multidrug resistance. Vet World 2019;12(4):504–521.

Jechalke S, Schierstaedt J, Becker M, Flemer B, Grosch R, Smalla K, Schikora A. *Salmonella* establishment in agricultural soil and colonization of crop plants depend on soil type and plant species. Front Microbiol 2019;10:1–17.

Jiménez SM, Salsi MS, Tiburzi MC, Pirovani ME. A comparison between broiler chicken carcasses with and without visible faecal contamination during the slaughtering process on hazard identification of *Salmonella* spp. J Appl Microbiol 2002;93(4):593–598.

Kaimowitz D. *Pobreza rural y medio ambiente en América Latina y el Caribe*, 2030 - Alimentación, agricultura y desarrollo rural en América Latina y el Caribe, Nº 35. Santiago de Chile: FAO, 2020.

Khalid S, Shahid M, Natasha, Bibi I, Sarwar T, Haidair A, Niazi NK. A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a

focus on low and high-income countries. Int J Environ Res Public Health 2018;15(5):895.

Kich JD, Coldebella A, Morés N, Nogueira M, Cardoso M, Fratamico PM, Call J, Fedorka-Cray P, Luchansky JB. Prevalence, distribution, and molecular characterization of *Salmonella* recovered from swine finishing herds and a slaughter facility in Santa Catarina, Brazil. Int J Food Microbiol 2011;151(3)307–313.

Kopittke PM, Menzies NW, Wang P, McKenna BA, Lombi E. (2019). Soil and the intensification of agriculture for global food security. Environ Int 2019;132:1–8.

Kottwitz L, Leão JA, Back A, Rodrigues D, Magnani M, de Oliveira T. Commercially laid eggs vs. discarded hatching eggs: Contamination by *Salmonella* spp. Braz J Microbiol 2013;44(2):367–370.

Kuri V, Madden RH, Collins MA. Hygienic quality of raw pork and chorizo (raw pork sausage) on retail sale in Mexico City. J Food Prot 1996;59(2):141–145.

Lapierre L, Cornejo J, Zavala S, Galarce N, Sánchez F, Benavides MB, Guzmán M, Sáenz L. Phenotypic and genotypic characterization of virulence factors and susceptibility to antibiotics in *Salmonella* Infantis strains isolated from chicken meat: First findings in Chile. Animals 2020;10(6):1–15.

Leiva A, Molina A, Redondo-Solano M, Artavia G, Rojas-Bogantes L, Granados-Chinchilla F. Pet food quality assurance and safety and quality assurance survey within the costa rican pet food industry. Animals 2019;9(11):1-25.

Lima B, Canto AC, Nascimento R, Franco R, Nascimento ER. Prevalência de *Salmonella* spp. na superfície no interior de linguiça frescal suína comercializada no Município de Niterói, Rio de Janeiro, Brasil. Rev Bras Med Vet 2011;33(3):133–136.

Lima E de, Pinto PS, Santos J dos, Vanetti MC, Bevilacqua P, Almeida L de, Pinto M, Dias, F. Isolamento de *Salmonella* sp e *Staphylococcus aureus* no processo do abate suíno como subsídio ao sistema de Análise de Perigos e Pontos Críticos de Controle - APPCC. Pesqui Vet Bras 2004;24(4):185–190.

Loayza SP. Quality control of beef in the municipal market of the city of Piñas in the Province of El Oro [Control de calidad de la carne de bovino en el mercado municipal de la ciudad de Piñas en la Provincia de El Oro]. Universidad Nacional de Loja, 2011. Available at: https://dspace.unl.edu.ec/jspui/bitstream/123456789/5387/1/tesis%20de%20control%20de%20calidad%20de%20carne.%20%20Santiago%20Loayza.pdf, accessed October 13, 2021.

Loiko M, de Paula C, Langone A, Rodrigues R, Cibulski S, Rodrigues R, Camargo A, Nero L, Mayer F, Tondo E. Genotypic and antimicrobial characterization of pathogenic bacteria at different stages of cattle slaughtering in southern Brazil. Meat Sci 2016;116:193–200.

Luiz A, Moreira F, Corrêa E, Falcão D. Monitoring of the dissemination of *Salmonella* in the chicken Frankfurt-sausage production line of a sausage factory in the state of São Paulo, Brazil. Mem Inst Oswaldo Cruz 2004;99(5):477–480.

Maffei DF, Moreira DA, Silva MB, Faria DB, Saldaña E, Ishimura I, Landgraf M, Franco BD. Assessing the relationship between organic farming practices and microbiological characteristics of organic lettuce varieties (*Lactuca sativa* L.) grown in Sao Paulo, Brazil. J Appl Microbiol 2019;127(1):237–247.

Mandrell RE. Enteric human pathogens associated with fresh produce: Sources, transport, and ecology. In: *Microbial Safety of Fresh Products*. Fan X, Niemira BA, Doona CJ, Feeherry FE, Gravani RB, eds. Iowa, USA: Blackwell Publishing and the Institute of Food Technologists, 2009, pp. 5-41.

Maradiaga M, Miller MF, Thompson L, Pond A, Gragg SE, Echeverry A, Garcia LG, Loneragan GH, Brashears MM. *Salmonella* in beef and produce from Honduras. J Food Prot 2015;78(3):498–502.

Marinheiro M, Ghizzi L, Cereser N, Lima H de, Timm C. Qualidade microbiológica de queijo mussarela em peça e fatiado. Semin Cienc Agrar 2015;36(3):1329–1334.

Martínez-Chávez L, Cabrera-Diaz E, Pérez-Montaño JA, Garay-Martínez LE, Varela-Hernández JJ, Castillo A, Lucia L, Ávila-Novoa MG, Cardona-López MA, Gutiérrez-González P, Martínez-Gonzáles NE. Quantitative distribution of *Salmonella* spp. and *Escherichia coli* on beef carcasses and raw beef at retail establishments. Int J Food Microbiol 2015;210:149-155.

Martínez A, Villoch A, Ribot A, Ponce P. Evaluación de la calidad e inocuidad de quesos frescos artesanales de tres regiones de una provincia de Cuba. Rev. Salud Anim 2013;35(3):210–213.

Martínez MM, Gómez CA. Compositional and hygienic quality of raw milk received in dairies in Sucre, Colombia. Biotecnol. Sector Agropecuario Agroind. 2013;11(2)93–100.

Mba-Jonas A, Culpepper W, Hill T, Cantu V, Loera J, Borders J, Saathoff-Huber L, Nsubuga J, Zambrana I, Dalton S, Williams I, Neil KP. A multistate outbreak of human *Salmonella* Agona infections associated with consumption of fresh, whole papayas imported from Mexico - United States, 2011. Clin Infect Dis 2018;66(11):1756–1761.

McDermott PF, Zhao S, Tate H. Antimicrobial resistance in nontyphoidal *Salmonella*. Microbiol Spectr 2018;6(4).

Mechesso AF, Moon DC, Kim SJ, Song HJ, Kang HY, Na SH, Choi JH, Kim HY, Yoon SS, Lim SK. Nationwide surveillance on serotype distribution and antimicrobial resistance profiles of non-typhoidal *Salmonella* serovars isolated from food-producing animals in South Korea. Int J Food Microbiol 2020;335:1–10.

Medeiros MA, de Oliveira DC, Rodrigues D, de Freitas DR. Prevalence and antimicrobial resistance of *Salmonella* in chicken carcasses at retail in 15 Brazilian cities. Pan Am J Public Health 2011;30(6):555–560.

Mejía L, Medina JL, Bayas R, Satan C, Villavicencio F, Zapata S, Matheu J, Wagenaar JA, González-Candelas F, Vinueza-Burgos C. Genomic epidemiology of *Salmonella* Infantis in Ecuador: From poultry farms to human infections. Front Vet Sci 2020;7:1–10.

Mejia L, Vela G, Zapata S. High occurrence of multiresistant *Salmonella* Infantis in retail meat in Ecuador. Foodborne Path Dis 2020;18(1):41–48.

Melo RT, Guimarães AR, Mendonça EP, Coelho LR, Monteiro GP, Fonseca BB, Rossi DA. Identifição sorológica e relação filogenética de *Salmonella* spp. de origem suína. Pesq Vet Bras 2011;31(12):1039–1044.

Merino L, Ronconi MC, Navia MM, Ruiz J, Sierra JM, Cech NB, Lodeiro NS, V. Analysis of the clonal relationship among clinical isolates of *Salmonella enterica* serovar Infantis by different typing methods. Rev Inst Med Trop Sao Paulo 2003;45(3):119–123.

Minharro S, Nascimento C, Galletti J, Merisse T, Feitosa A, Santos H, Dias F, Santana E, Baldani C, Andrade M. Antimicrobial susceptibility of *Salmonella* serovars isolated from edible offal and carcasses of slaughtered poultry in the state of Tocantins, Brazil. Semin Cienc Agrar 2015;36(4):2661–2669.

Miranda JM, Mondragón AC, Martinez B, Guarddon M, Rodriguez JA. Prevalence and antimicrobial resistance patterns of *Salmonella* from different raw foods in Mexico. J Food Prot 2009;72(5):966–971.

Mogollón DC, Rodríguez VE, Verjan N. Prevalence and molecular identification of *Salmonella* spp. isolated from commercialized eggs at Ibague, Colombia. Rev Salud Anim 2016;38(3):164–172.

Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA, PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 2015;4(1):1–9.

Molina A, Granados-Chinchilla F, Jiménez M, Acuña-Calvo MT, Alfaro M, Chavarría G. Vigilance for *Salmonella* in feedstuffs available in Costa Rica: Prevalence, serotyping and tetracycline resistance of isolates obtained from 2009 to 2014. Foodborne Path Dis 2015;13(3)119–127.

Monteiro E, Costa P da, Manfrin L, Freire D, Silva IC da, Orsi D. Qualidade microbiológica de carne bovina moída comercializada em supermercados do Distrito Federal, Brasil. Rev Bras Hig Sanid Anim 2018;12(4):520-530.

Morales-Hernández L, Hernández-Anguiano AM, Cháidez-Quiroz C, Rendón-Sánchez G, Suslow TV. Detección de *Salmonella* spp. en melón cantaloupe en unidades de producción y unidad de empaque. Agricultura Técnica en México 2009;35(2):135–145.

Morales G, Blanco L, Arias ML, Chaves C. Evaluación de la calidad bacteriológica de tilapia fresca (*Oreochromis niloticus*) proveniente de la Zona Norte de Costa Rica. Arch Latinoam Nutr 2004;54(4):433-437.

Morillo N, Rondón I, Valero-Leal K, Uzcátegui-Bracho S. Bacterias patógenas en carne de cangrejo comercializado fresco y pasteurizado. Maracaibo, Venezuela. Revista Científica FCV-LUZ 2007;17(3):288–293.

Moura MS, Oliveira RP, Melo RT, Mendonça EP, Fonseca BB, Rossi DA. (2014). Genes de virulência e diversidade genética em *Salmonella* spp. isoladas de amostras de origem

suína. Arq Bras Med Vet Zootec 2014;66(5):1367–1375.

Muñoz S, Vilca M, Ramos D, Lucas J. Frecuencia de Enterobacterias en verduras de consumo crudo expendidas en cuatro mercados de Lima, Perú. Rev Inv Vet Perú 2013;24(3):300–306.

Mürmann L, Corbellini LG, Collor A, Cardoso M. Quantitative risk assessment for human salmonellosis through the consumption of pork sausage in Porto Alegre, Brazil. J Food Prot 2011;74(4):553–558.

Narváez-Bravo C, Miller MF, Jackson T, Jackson S, Rodas-González A, Pond K, Echeverry A, Brashears, MM. *Salmonella* and *Escherichia coli* O157:H7 prevalence in cattle and on carcasses in a vertically integrated feedlot and harvest plant in Mexico. J Food Prot 2013a;76(5):786–795.

Narváez-Bravo C, Rodas-González A, Fuenmayor Y, Flores-Rondon C, Carruyo G, Moreno M, Perozo-Mena A, Hoet AE. *Salmonella* on feces, hides and carcasses in beef slaughter facilities in Venezuela. Int J Food Microbiol 2013b;166(2):226–230.

Narváez CA, Parra KC, Huerta-Leidenz N, Rodas-González A, Moreno LA de. Aislamiento de *Salmonella* y *Escherichia coli* patógenas durante el procesamiento de hamburguesas en una pequeña planta de Maracaibo, Venezuela. Revista Cientifica FCV-LUZ 2005;15(6):551–559.

Nascimento MS, Carminati JA, Silva IC, Silva DL, Bernardi AO, Copetti MV. *Salmonella*, *Escherichia coli* and *Enterobacteriaceae* in the peanut supply chain: From farm to table. Food Res Int 2018;105:930–935.

Neitzke, DC, Roza C da, Hart F. Segurança dos alimentos: contaminação por *Salmonella* sp. no abate de suínos. Braz J Food Technol 2017;20:1-7.

Oliveira MA de, Souza VM de, Bergamini AM, De Martinis EC. Microbiological quality of ready-to-eat minimally processed vegetables consumed in Brazil. Food Control 2011;22(8):1400–1403.

Orozco L, Iturriaga MH, Tamplin ML, Fratamico PM, Call JE, Luchansky JB, Escartin EF. Animal and environmental impact on the presence and distribution of *Salmonella* and *Escherichia coli* in hydroponic tomato greenhouses. J Food Prot 2008;71(4):676–683.

Orozco L, Rico-Romero L, Escartín EF. Microbiological profile of greenhouses in a farm producing hydroponic tomatoes. J Food Prot 2008;71(1):60–65.

Paim D, Pissetti C, Vieira TR, Werlang G, Freitas Costa E de, Kich J, Cardoso M. (2019). Enumeration, antimicrobial resistance and typing of *Salmonella enterica*: Profile of strains carried in the intestinal contents of pigs at slaughter in Southern Brazil. Acta Sci Vet 2019;47:1636.

Palmeira A, Santos L dos, Borsoi A, Rodrigues LB, Calasans M, Nascimento V do. Serovars and antimicrobial resistance of *Salmonella* spp. Isolated from turkey and broiler carcasses in Southern Brazil between 2004 and 2006. Rev Inst Med Trop Sao Paulo 2016;58(19):1–5.

Perez-Montaño JA, Gonzalez-Aguilar D, Barba J, Pacheco-Gallardo C, Campos-Bravo CA, Garcia S, Heredia NL, Cabrera-Diaz E. Frequency and antimicrobial resistance of *Salmonella* serotypes on beef carcasses at small abattoirs in Jalisco State, Mexico. J Food Prot 2012;75(5):867–873.

Perin AP, Martins B, Barreiros MA, Yamatogi R, Nero LA, Bersot L. Occurrence, quantification, pulse types, and antimicrobial susceptibility of *Salmonella* sp. isolated from chicken meat in the state of Paraná, Brazil. Braz J Microbiol 2019;51(1):335–345.

Plaza-Ibarra LA, Morales MF. Microbiological analysis of fresh cheeses sold in the presence or absence of *Listeria* and *Salmonella* [Análisis microbiológico en quesos frescos que se expenden en presencia o ausencia de *Listeria y Salmonella*]. Repositorio de la Escuela Superior Politécnica del Litoral. Escuela Superior Politécnica del Litoral (ESPOL), 2001. Available at: https://www.dspace.espol.edu.ec/bitstream/123456789/24428/1/resumen%20luis%20plaza.pdf, accessed October 13, 2021.

Procura F, Bueno DJ, Bruno SB, Rogé AD. Prevalence, antimicrobial resistance profile and comparison of methods for the isolation of *Salmonella* in chicken liver from Argentina. Food Res Int 2017;119:541–546.

Puig Y, Espino M, Leyva V, Aportela N, Machín M, Soto P. (2011). Serovariedades y patrones de susceptibilidad a los antimicrobianos de cepas de *Salmonella* aisladas de alimentos en Cuba. Pan Am J Public Health 2011;30(6):561–565.

Queiroz M, Rossi BF, Castilho I, Rall VL. (2018). Hygienic-sanitary quality of Minas fresh cheese sold in the city of Botucatu, São Paulo. Arq Inst Biol 2018;84:1–6.

Quintana-Ospina G, Holguin-Cespedes G, Rodriguez-Rodriguez V, Verjan-Garcia N. Detection of *Salmonella* spp. antigens in Tolima poultry products by Western Blot. Veterinaria y Zootecnia 2018:12(1):72–83.

Quiñones-Ramírez EI, Vázquez-Salinas C, Pedroche FF, Moreno-Sepúlveda L, Rodas-Suárez OR. Presencia de los géneros *Vibrio* y *Salmonella*, y detección de coliformes faecales en almejas del Golfo de México. Hidrobiológica 2000;10(2):131–138.

Quiroz-Santiago C, Rodas-Suárez OR, Vázquez CR, Fernández FJ, Quiñones-Ramírez EI, Vázquez-Salinas C. Prevalence of *Salmonella* in vegetables from Mexico. J Food Prot 2009;72(6):1279–1282.

Rall VL, Martin JG, Candeias JM, Cardoso KF, Silva M da, Rall R, Araújo Júnior J. Pesquisa de *Salmonella* e das condições sanitárias em frangos e lingüiças comercializados na cidade de Botucatu. Braz J Vet Res An Sci 2009;46(3):167-174.

Ramírez-Hernández A, Varón-García A, Sánchez-Plata MX. Microbiological profile of three commercial poultry processing plants in Colombia. J Food Prot 2017;80(12):1980–1986.

Rangel-Vargas E, Gómez-Aldapa CA, Torres-Vitela MR, Villarruel-López A, Gordillo-Martínez AJ, Castro-Rosas J. Presence and correlation of some enteric indicator bacteria, diarrheagenic *Escherichia coli* pathotypes, and *Salmonella* serotypes in alfalfa

sprouts from local retail markets in Pachuca, Mexico. J Food Prot 2015;78(3):609–614.

Regalado-Pineda ID, Rodarte-Medina R, Resendiz-Nava CN, Saenz-Garcia CE, Castañeda-Serrano P, Nava GM. Three-year longitudinal study: Prevalence of *Salmonella enterica* in chicken meat is higher in supermarkets than wet markets from Mexico. Foods 2020;9(3):1-10.

Reges JT, Borges AC, Silva CJ da, Santos S dos, Costa AC, Tavares W, Jesus M de, Silva S da. Qualidade microbiológica e físico química do queijo mussarela a granel comercializadas em Jataí (Goiás, Brasil). Rev Colomb Investig Agroindustriales 2017;4:69-77.

Rengel A, Mendoza S. (1984). Isolation of *Salmonella* from raw chicken in Venezuela. J Food Prot 1984;47(3):213–216.

Reuben A, Treminio H, Arias ML, Chaves C. Presencia de *Escherichia coli* O157:H7, *Listeria monocytogenes* y *Salmonella* spp. en alimentos de origen animal en Costa Rica. Arch Latinoam Nutr 2004;54(1):5-12.

Rezende AC, Crucello J, Moreira R, Silva B, Sant'Ana A. Incidence and growth of *Salmonella enterica* on the peel and pulp of avocado (*Persea americana*) and custard apple (*Annona squamosa*). Int J Food Microbiol 2016;235:10–16.

Ristori C, Rowlands RE, Martins C, Barbosa ML, Santos LF dos, Jakabi M, Melo Franco BD de. Assessment of consumer exposure to *Salmonella* spp., *Campylobacter* spp., and shiga toxin-producing *Escherichia coli* in meat products at retail in the city of Sao Paulo, Brazil. Foodborne Path Dis 2017;14(8):447–453.

Rodriguez-Roque SM, Attie-Habelrih MG, Figueroa-Espinosa RA, Thomas LE, Escalona-Pacheco AJ, Báez-Ramírez EA. Análisis microbiológico de muestras de kibbeh crudo revela la presencia de bacterias enteropatógenas. Salud Publ Mex 2018;60(1):105–106.

Rodriguez JM, Rondón IS, Verjan N. Serotypes of *Salmonella* in broiler carcasses marketed at Ibague, Colombia. Rev Bras Cienc Avic 2015;17(4):545–552.

Rondón-Barragán IA, Arcos E, Mora-Cardona L, Fandiño C. Characterization of *Salmonella* species from pork meat in Tolima, Colombia. Rev Colomb Cienc Pecu 2015;28:74–82.

Rubio MS, Martínez JF, Hernández R, Bonilla C, Méndez RD, Núñez JF, Echeverry A, Brashears M. Detección de *Listeria monocytogenes*, *Salmonella* y *Yersinia enterocolitica* en carne de res en puntos de venta en México. Rev Mex Cienc Pecu 2013;4(1):107–115.

Ruiz-Roldán L, Martínez-Puchol S, Gomes C, Palma N, Riveros M, Ocampo K, Durand D, Ochoa T, Ruiz J, Pons M. Presence of multidrug resistant *Enterobacteriaceae* and *Escherichia coli* in meat purchased in traditional markets of Lima. Rev Peru Med Exp Salud Publica 2018;35(3):425–432.

Ruschel CK, Carvalho HH, Souza RB de, Tondo EC. Qualidade microbiológica e físico-química de sucos de laranja comercializados nas vias públicas de Porto Alegre/RS. Ciência e Tecnologia de Alimentos 2001;21(1):94–97.

Salazar GA, Guerrero-López R, Lalaleo L, Avilés-Esquivel D, Vinueza-Burgos C, Calero-Cáceres W. Presence and diversity of *Salmonella* isolated from layer farms in central Ecuador. F1000Research 2019;8:235-246.

Salvatierra G, Pinto C, Inga E, Siuce J, Calle S. Detection of *Salmonella* sp in pork carcasses in slaughterhouses in Lima, Peru. Rev Inv Vet Perú 2015;26(4):682–688.

Sánchez MJ. Determination of the prevalence of enterobacteria of the genus *Salmonella* spp. in fresh chicken eggs from poultry companies in the province of Tungurahua [Determinación de la prevalencia de enterobacterias del género *Salmonella* spp. en huevos frescos de gallina de empresas avícolas de la provincia de Tungurahua]. Universidad Central del Ecuador, 2013. Available at: http://www.dspace.uce.edu.ec/bitstream/25000/1157/1/T-UCE-0014-36.pdf, accessed October 13, 2021.

Sánchez XM. Molecular identification of *Salmonella* spp. in an integrated broiler production system [Identificación molecular de *Salmonella* spp. en un sistema integrado de producción de pollos de engorde]. Universidad Central del Ecuador, 2016. Available at: http://www.dspace.uce.edu.ec/bitstream/25000/11765/1/T-UCE-0014-036-2016.pdf, accessed October 13, 2021.

Sanchez-Maldonado AF, Aslam M, Service C, Narváez-Bravo C, Avery BP, Johnson R, Jones TH. Prevalence and antimicrobial resistance of *Salmonella* isolated from two pork processing plants in Alberta, Canada. Int J Food Microbiol 2017;241:49–59.

Sant'Ana AS, Landgraf M, Destro MT, Franco B. Prevalence and counts of *Salmonella* spp. in minimally processed vegetables in São Paulo, Brazil. Food Microbiol 2011;28(6):1235–1237.

Santos D, Junior A, Fernandes S, Tavechio AT, Amaral LA do. *Salmonella* em carcaças de frango congeladas. Pesqui Vet Bras 2000;20(1):39–42.

Santos FF, Aquino MH, Nascimento ER, Abreu DL, Gouvêa R, Rodrigues DP, Reis EM, Araújo MS, Pereira VL. Chicken feet bacteriological quality at 4 steps of technological processing. Poult Sci 2011;90(12):2864–2868.

Santos R dos, Xavier R, Oliveira T de, Leite R, Figueiredo HC, Leal CA. Occurrence, genetic diversity, and control of *Salmonella enterica* in native Brazilian farmed fish. Aquaculture 2019;501:304–312.

Seixas F, Tochetto R, Ferraz SM. Presença de *Salmonella* sp. em carcaças suínas amostradas em diferentes pontos da linha de processamento. Ciênc Anim Bras 2009;10(2):634–640.

Silva C, Calva E, Maloy S. One Health and food-borne disease: *Salmonella* transmission between humans, animals, and plants. Microbiol Spectr 2014;1(3):1–9.

Silva LE, Dias V, Ferronatto A, Guerra P, Berno L, Triches N, Kich J, Corbellini LG, Cardoso M. Longitudinal dissemination of *Salmonella enterica* clonal groups through the slaughter process of *Salmonella*-positive pig batches. J Food Prot 2012;75(9):1580–1588.

Silva LE, Gotardi CP, Vizzotto R, Kich JD, Cardoso MR. Infecção por *Salmonella enterica* em suínos criados em um sistema integrado de produção do sul do Brasil. Arq Bras Med Vet Zootec 2006;58(4):455–461.

Silva R da, Gonçalves G, Lazzari AM, Mulinari F. Prevalência de *Salmonella* spp. em suínos abatidos em um frigorífico do Distrito Federal determinada pela técnica de PCR. Braz J Food Technol 2018;21:1-6.

Solano CS. Incidence of *Salmonella* types in creole hen eggs sold in the markets of Guaranda, Chimbo and San Miguel [Incidencia de los tipos de *Salmonella* en los huevos de gallina criolla que se expenden en los mercados de Guaranda, Chimbo y San Miguel]. Universidad Estatal de Bolívar, 2016. Available at: http://dspace.ueb.edu.ec/handle/123456789/1632, accessed July 9, 2021.

Soria MC, Soria MA, Bueno DJ, Godano EI, Gómez SC, ViaButron IA, Padin VM, Rogé AD. *Salmonella* spp. contamination in commercial layer hen farms using different types of samples and detection methods. Poult Sci 2017;*96*(8):2820–2830.

Soto-Varela ZE, Gutiérrez CG, Moya Y de, Mattos R, Bolívar-Anillo HJ, Villarreal JL. Detección molecular de *Salmonella* spp., *Listeria* spp. y *Brucella* spp. en queso artesanal fresco comercializado en Barranquilla: un estudio piloto. Biomedica 2018;38:30–36.

Souza IA de, Giovannetti AC, Santos LG, Gandra SO, Martins M, Ramos A. Qualidade microbiológica de queijo Minas frescal comercializado na Zona da Mata Mineira. Rev Inst Laticínios Cândido Tostes 2017;72(3):152–162.

Spricigo DA, Matsumoto SR, Espíndola ML, Ferraz SM. Prevalência, quantificação e resistência a antimicrobianos de sorovares de *Salmonella* isolados de lingüiça frescal suína. Ciencia e Tecnologia de Alimentos 2008;28(4):779–785.

Spricigo DA, Matsumoto SR, Espíndola ML, Vaz EK, Ferraz SM. Prevalência e perfil de resistência a antimicrobianos de sorovares de *Salmonella* isolados de lingüiças suínas tipo frescal em Lages, SC. Arq Bras Med Vet Zootec 2008;60(2):517–520.

Tack B, Vanaenrode J, Verbakel JY, Toelen J, Jacobs J. Invasive non-typhoidal *Salmonella* infections in sub-Saharan Africa: A systematic review on antimicrobial resistance and treatment. BMC Medicine 2020;18(1):1–22.

Takayanagui OM, Oliveira CD, Bergamini A, Capuano DM, Okino M, Febrônio L, Castro A, Oliveira MA, Ribeiro E, Takayanagui AM. Monitoring of vegetables commercially sold in Ribeirão Preto, SP, Brazil. Rev Soc Bras Med Trop 2001;34(1):37–41.

Takayanagui OM, Febrônio LH, Bergamini AM, Okino MH, Silva A, Santiago R, Capuano DM, Oliveira MA, Takayanagui AM. Fiscalização de hortas produtoras de verduras do município de Ribeirão Preto, SP. Rev Soc Bras Med Trop 2000;33(2):169–174.

Talavera M, Reyes NE, Lagunas S, Fernández P, Morales V, Soriano E. (2011). Variabilidad genética de aislamientos de *Salmonella typhimurium* (grupo B) obtenidos de hígados de pollo destinados para consumo humano. Rev Mex Cienc Pecu 2011;2(4):371–380.

Tejada TS, Silva CS, Lopes NA, Silva DT, Agostinetto A, Silva EF, Menezes DB, Timm CD.

DNA profiles of *Salmonella* spp. isolated from chicken products and from broiler and human feces. Rev Bras Cienc Avic 2016;18(4):693–700.

Terzolo H. *Salmonella* Enteritidis ¿Vacunar o no vacunar? In: *Avícola Porcinos – 8º Seminario Internacional*. Balcarce, Argentina, 2010.

Tessari E, Cardoso AL, Kanashiro AM, Stoppa GF, Luciano RL, de Castro A. Ocorrência de *Salmonella* spp. em carcaças de frangos industrialmente processadas, procedentes de explorações industriais do Estado de São Paulo, Brasil. Ciencia Rural 2008;38(9):2557–2560.

Tessmann C, Zocche F, De Lima A, Bassani M, Lopes G, Da Silva W. Ocorrência e perfil de sensibilidade a antibióticos de *Salmonella* spp. isolada em cortes de carne suína comercializados en feiras-livres de Pelotas (RS). Bol Cent Pesqui Process Aliment 2008;26(2):307–313.

Tirolli IC, Da Costa C. Occurrence of *Salmonella* spp. in chicken carcasses commercialized in open markets in the city of Manaus - Amazonas. Acta Amaz 2006;36(2):205–208.

Tondo EC, Ritter AC. *Salmonella* and salmonellosis in Southern Brazil: A review of the last decade, In: *Salmonella: Classification, Genetics and Disease Outbreaks*. Monte A, De Santos P, eds. New York: Nova Science Publishers, Inc., 2012, pp. 175–192.

Torres-Vitela MR, Escartin EF, Castillo A. Risk of salmonellosis associated with consumption of chocolate in Mexico. J Food Prot 1995;58(5):478–481.

Torres-Vitela MD, Gómez Aldapa CA, Cerna-Cortes JF, Villarruel-López A, Rangel-Vargas E, Castro-Rosas J. Presence of indicator bacteria, diarrhoeagenic *Escherichia coli* pathotypes and *Salmonella* in fresh carrot juice from Mexican restaurants. Lett Appl Microbiol 2012a;56(3):180-185.

Torres-Vitela MR, Mendoza-Bernardo M, Castro-Rosas J, Gomez-Aldapa CA, Garay-Martinez LE, Navarro-Hidalgo V, Villarruel-López A. (2012). Incidence of *Salmonella*, *Listeria monocytogenes*, *Escherichia coli* O157:H7, and staphylococcal enterotoxin in two types of Mexican fresh cheeses. J Food Prot 2012b;75(1):79–84.

Ulloa J, González M, Hernández C, Villanueva MP, Fernández H. *Salmonella* Enteritidis in chicken carcasses and giblets in Southern Chile. J Infect Dev Ctries 2010;4(2):107–109.

Valadez F, Hernández MC, García EM, Ramírez LY, Flores JF, Rodríguez GC, Acosta RI. Microbiological quality of ready-to-eat street-vended flavored waters and fruits salads in Reynosa, Tamaulipas, Mexico. Acta Univ 2017;*27*(6):3–9.

Varela-Guerrero JA, Talavera-Rojas M, Gutiérrez-Castillo AC, Reyes-Rodríguez NE, Vázquez-Guadarrama J. Phenotypic-genotypic resistance in *Salmonella* spp. isolated from cattle carcasses from the north central zone of the State of Mexico. Trop Anim Health Prod 2013;45(4):995–1000.

Viana C, Sereno M, Pegoraro K, Yamatogi R, Call DR, Bersot L, Nero LA. Distribution, diversity, virulence genotypes and antibiotic resistance for *Salmonella* isolated from a Brazilian pork production chain. Int J Food Microbiol 2019;310:1-7.

Vieira RH, de Lima E, Sousa D, dos Reis E, Costa R, Rodrigues D. *Vibrio* spp. and *Salmonella* spp., presence and susceptibility in crabs *Ucides cordatus*. Rev Inst Med Trop Sao Paulo 2004;46(4):179–182.

Villagómez SD. Isolation and serotyping of *Salmonella* Enteritidis, Typhimurium, and Infantis in chicken carcasses destined for human consumption in an industrialized slaughterhouse in the province of Pichincha [Aislamiento y serotipificación de *Salmonella* Enteritidis, Typhimurium e Infantis en carcasas de pollo destinadas para consumo humano en un camal industrializado de la provincia de Pichincha]. Universidad Central del Ecuador, 2015. Available at: http://www.dspace.uce.edu.ec/bitstream/25000/6677/1/T-UCE-0014-027.pdf, accessed October 13, 2021.

Villalpando-Guzmán S, Vázquez-Quiñones CR, Natividad-Bonifacio I, Curiel-Quesada E, Quiñones-Ramírez EI, Vázquez-Salinas C. Frecuencia, susceptibilidad antimicrobiana y patrón de adherencia de *Salmonella enterica* aislada de carne de pollo, res y cerdo de la ciudad de México. Rev Chilena Infectol 2017;34(5):458–466.

Vinueza-Burgos C, Baquero M, Medina J, De Zutter L. Occurrence, genotypes and antimicrobial susceptibility of *Salmonella* collected from the broiler production chain within an integrated poultry company. Int J Food Microbiol 2019;299:1–7.

Volcão L, Marques J, Bernardi E, Ribeiro G. Saúde e segurança alimentar: isolamento e análise do perfil de suscetibilidade de bactérias patogênicas de alimentos. R Epidemiol Control Infec 2016;6(4):1–6.

Voss-Rech D, Vaz CS, Alves L, Coldebella A, Leao JA, Rodrigues DP, Back A. A temporal study of *Salmonella enterica* serotypes from broiler farms in Brazil. Poult Sci 2015;94(3):433–441.

Weiler N, Orrego M, Alvarez M, Huber C, Ortiz F, Nuñez L, Piris L, Perez J. (2017). First results of the comprehensive surveillance of the antimicrobial resistance of foodborne pathogens, *Campylobacter* spp. and *Salmonella* spp., in three different populations. Paraguay, 2011-2012. Mem Inst Investig Cienc Salud 2017;15(2):64–72.

Werlang G, Haubert L, Peter C, Cardoso M. Isolation of *Salmonella* Typhimurium, *Listeria monocytogenes* and coagulase-positive *Staphylococcus* from salami sold at street fairs in Porto Alegre, Brazil. Arq Inst Biol 2019;86:1–6.

WHO. WHO's first ever global estimates of foodborne diseases find children under 5 account for almost one third of deaths. 2015. Available at: https://www.who.int/en/news-room/detail/03-12-2015-who-s-first-ever-global-estimates-of-foodbornediseases-find-children-under-5-account-for-almost-one-third-ofdeaths, accessed August 27, 2020.

WHO. Critically Important Antimicrobials for Human Medicine – 5th rev. Geneva: World Health Organization, 2017.

WHO. *Salmonella* (non-typhoidal). 2018. Available at: https://www.who.int/news-room/fact-sheets/detail/*Salmonella*-(nontyphoidal), accessed August 27, 2020.

Xu H, Zhang W, Guo C, Xiong H, Chen X, Jiao X, Su J, Mao L, Zhao Z, Li Q. Prevalence, serotypes, and antimicrobial resistance profiles among *Salmonella* isolated from food catering workers in Nantong, China. Foodborne Path Dis 2019;16(5):346–351.

Yamaguchi M, Zanqueta É, Moarais J, El Ghoz H, Silvério KI. Qualidade microbiológica de alimentos e de ambientes de trabalho: pesquisa de *Salmonella* e *Listeria*. Rev em Agronegócio e Meio Ambient 2013;6(3):417–434.

Zaidi MB, McDermott PF, Fedorka-Cray P, Leon V, Canche C, Hubert SK, Abbot J, León M, Zhao S, Headrick M, Tollefson L. Nontyphoidal *Salmonella* from human clinical cases, asymptomatic children, and raw retail meats in Yucatan, Mexico. Clin Infect Dis 2006;42(1):21–28.

Tables (Chapter 1)

TABLE 1. PREVALENCE OF NONTYPHOIDAL *SALMONELLA* IN VARIOUS FOOD PRODUCTS FROM LATIN AMERICA

Country	Analyzed foods	Prevalence (%)	References
Argentina			
	Chicken meat and giblets	3.2-20	Jiménez *et al*. (2002); Favier *et al*. (2013); Procura *et al*. (2019)
	Pork meat	4.5	Colello *et al*. (2018)
	Pork sausages	6.6	Favier *et al*. (2013)
	Bovine meat	15.9, 34	Curi de Montbrun *et al*. (1972); Barril *et al*. (2019)
	Eggs	3.3	Favier *et al*. (2013)
	Hen feed	4.6	Soria *et al*. (2017)
	Crushed bone meal	1.3	Harvey and Price (1978)
Brazil			
	Chicken meat	1.6-68	Santos *et al*. (2000, 2011); Baú *et al*. (2001); Luiz *et al*. (2004); Carvalho and Cortez (2005); Hernandez *et al*. (2005); Tirolli and Da Costa (2006); Tessari *et al*. (2008); Asensi *et al*. (2009); Rall *et al*. (2009); Medeiros *et al*. (2011); Cossi *et al*. (2012); Yamaguchi *et al*. (2013); Minharro *et al*. (2015); Dias *et al*. (2016); Tejada *et al*. (2016); Ristori *et al*. (2017); Baptista *et al*. (2018); da Cunha-Neto *et al*. (2018); Bersot *et al*. (2019b); Perin *et al*. (2019)
	Pork meat	0.8-93.3	de Lima *et al*. (2004); Borowsky *et al*. (2007); Tessmann *et al*. (2008); Seixas *et al*. (2009); Kich *et al*. (2011); Silva *et al*. (2012); Moura *et al*. (2014); Corbellini *et al*. (2016); Cabral *et al*. (2017); Neitzke *et al*. (2017); da Silva *et al*. (2018); Bersot *et al*. (2019a); Paim *et al*. (2019); Viana *et al*. (2019)
	Bovine meat	0.03-60	Carvalho and Cortez (2005); Yamaguchi *et al*. (2013); Cossi *et al*. (2014); Loiko *et al*. (2016); Volcão *et al*. (2016); Bier *et al*. (2018); Monteiro *et al*. (2018)

	Sausages	4.4-12.8	Benetti *et al*. (2013); Freire *et al*. (2019); Werlang *et al*. (2019)
	Chicken sausages	16, 26	Carvalho and Cortez (2005); Cabral *et al*. (2014)
	Pork sausages	5.8-66	Castagna *et al*. (2005); Spricigo *et al*. (2008a, 2008b); Fai *et al*. (2011); Lima *et al*. (2011); Mürmann *et al*. (2011); Cabral *et al*. (2014); Ristori *et al*. (2017); Cavalin *et al*. (2018)
	Other meat[a]	3.4, 30.8	Hofer *et al*. (2000); Fernandes *et al*. (2009)
	Eggs	1.5-68	Evêncio-Luz *et al*. (2012); Kottwitz *et al*. (2013); de Freitas *et al*. (2014); Galvão *et al*. (2018)
	Charqui	28	Abrantes *et al*. (2014)
	Dairy products	0.4-40	Yamaguchi *et al*. (2013); Marinheiro *et al*. (2015); Reges *et al*. (2017); de Souza *et al*. (2017); Queiroz *et al*. (2018); Carvalho *et al*. (2019)
	Farmed fish, seafood	6.9, 15.2	Vieira *et al*. (2004); dos Santos *et al*. (2019)
	Vegetables	0.4-25	Takayanagui *et al*. (2000, 2001); Fröder *et al*. (2007); de Oliveira *et al*. (2011); Sant'Ana *et al*. (2011); Beltrão *et al*. (2017); Carvalho *et al*. (2019); da Cruz *et al*. (2019); Maffei *et al*. (2019)
	Fruit juice and pulp	1.5-33.3	Ruschel *et al*. (2001); (Ferreira and Junqueira (2007); Rezende *et al*. (2016)
	Peanuts	2.2	Nascimento *et al*. (2018)
	Spices	67	Costa *et al*. (2020)
	Jelly	20	Carvalho *et al*. (2019)
	Animal feed	2.6-66.7	Albuquerque *et al*. (1999); Silva *et al*. (2006); Melo *et al*. (2011); Moura *et al*. (2014); Bersot *et al*. (2019a)
Chile			
	Chicken meat and giblets	0.4-24.8	Alexandre *et al*. (2000); Ulloa *et al*. (2010); Lapierre *et al*. (2020)
	Eggs	0.09	Alexandre *et al*. (2000)
Colombia			

	Chicken meat and giblets	12.5-83.3	Espinal *et al*. (2006); Donado-Godoy *et al*. (2012, 2015); Rodriguez *et al*. (2015); Ramírez-Hernández *et al*. (2017); Quintana-Ospina *et al*. (2018)
	Pork meat	3.3-8.1	Espinal *et al*. (2006); Rondón-Barragán *et al*. (2015)
	Bovine meat	40.5	Espinal *et al*. (2006)
	Sausages	17.6	Espinal *et al*. (2006)
	Eggs	2.9, 22.2	Mogollón *et al*. (2016); Quintana-Ospina *et al*. (2018)
	Dairy products	1.8-62.9	Espinal *et al*. (2006); Martinez and Gomez (2013); Soto-Varela *et al*. (2018)
	Ready-to-eat food	0.3-2.7	Espinal *et al*. (2006); Forero *et al*. (2017)
	Drinking water	1.4	Espinal *et al*. (2006)
Costa Rica			
	Chicken giblets	15	Reuben *et al*. (2004)
	Bovine meat	3.6	Chaves and Brashears (2015)
	Eggs	18.7, 25.3	Arias *et al*. (1996)
	Tilapia	2	Morales *et al*. (2004)
	Animal feed, feedstuffs	1.3-26.7	Molina *et al*. (2015); Leiva *et al*. (2019)
Cuba			
	Dairy products	19	Martínez *et al*. (2013)
Ecuador			
	Chicken meat	55.5-88	Vinueza-Burgos *et al*. (2019); Mejía *et al*. (2020a)
	Chicken skin	15-80	Villagómez (2015); Sánchez (2016)
	Bovine meat	66.7	Loayza (2011)
	Sausages	25, 30.6	Campoverde (2015)
	Meat[b]	38.1	Mejia *et al*. (2020b)
	Eggs	0.01, 2	Sánchez (2013); Solano (2016)
	Dairy products	13.7	Plaza-Ibarra and Morales (2001)

	Seafood	7.1	Gecan *et al*. (1994)
	Animal feed, feedstuffs	0.5-33	Sánchez (2016); Salazar *et al*. (2019); Vinueza-Burgos *et al*. (2019)
Honduras			
	Bovine meat	10.1	Maradiaga *et al*. (2015)
	Vegetables and fruits	2.1	
Mexico			
	Chicken meat and giblets	1.34-47.7	Bello-Pérez *et al*. (1990); Zaidi *et al*. (2006); Miranda *et al*. (2009); Talavera et al. (2011); Villalpando-Guzmán *et al*. (2017); Regalado-Pineda *et al*. (2020)
	Pork meat and giblets	1.8-76	Bello-Pérez *et al*. (1990); Kuri *et al*. (1996); Zaidi *et al*. (2006); Miranda *et al*. (2009); Villalpando-Guzmán *et al*. (2017)
	Bovine meat and giblets	1.19-71	Bello-Pérez *et al*. (1990); Heredia *et al*. (2001); Zaidi *et al*. (2006); Miranda *et al*. (2009); Perez-Montaño *et al*. (2012); Cabrera-Diaz *et al*. (2013); Narváez-Bravo *et al*. (2013a); Rubio *et al*. (2013); Varela-Guerrero *et al*. (2013); Martínez-Chávez *et al*. (2015); Villalpando-Guzmán *et al*. (2017)
	Charqui and sausages	11.1-60	Bello-Pérez *et al*. (1990); Kuri *et al*. (1996); Becerril *et al*. (2019)
	Chorizo	88.3	Escartin *et al*. (1999)
	Dairy products	4-30.3	Miranda *et al*. (2009); Torres-Vitela *et al*. (2012b); Guzman-Hernandez *et al*. (2016); Chávez-Martínez *et al*. (2019)
	Seafood	0.9, 11	Bello-Pérez *et al*. (1990); Quiñones-Ramírez *et al*. (2000)
	Vegetables	1.8-31	Gallegos-Robles *et al*. (2008); Orozco *et al*. (2008a, 2008b); Quiroz-Santiago *et al*. (2009); Castro-Rosas *et al*. (2010, 2011); Castañeda-Ramírez *et al*. (2011); Avila-Vega *et al*. (2014); Rangel-Vargas *et al*. (2015); Gutiérrez-Alcántara *et al*. (2016); Gómez-Aldapa *et al*. (2017)
	Vegetable salads	6.8-21.8	Miranda *et al*. (2009); Gómez-Aldapa *et al*. (2013a, 2017)
	Vegetable and fruit juice	3.9-14.3	Castillo *et al*. (2006); Castro-Rosas *et al*. (2010); Torres-Vitela *et al*. (2012a); Gómez-Aldapa *et al*. (2014)

	Fruits	12-40	Espinoza-Medina *et al*. (2006); Gallegos-Robles *et al*. (2008); Morales-Hernández *et al*. (2009); Mba-Jonas *et al*. (2018)
	Fruit salads and flavored waters	15, 16.6	Valadez *et al*. (2017)
	Eggs	3, 16	Guzmán-Gómez *et al*. (2013)
	Chocolate	1.8, 4.5	Torres-Vitela *et al*. (1995)
	Taco dressing	5	Estrada-Garcia *et al*. (2004)
	Ready-to-eat food	2, 3.27	Bello-Pérez *et al*. (1990); Gómez-Aldapa *et al*. (2013b)
Paraguay			
	Chicken meat	7	Weiler *et al*. (2017)
Peru			
	Chicken meat	28.1	Ruiz-Roldán *et al*. (2018)
	Pork meat	6.3, 6.6	Salvatierra *et al*. (2015); Ruiz-Roldán *et al*. (2018)
	Bovine meat	2.3	Ruiz-Roldán *et al*. (2018)
	Seafood	50	Gecan *et al*. (1994)
	Vegetables	10	Muñoz *et al*. (2013)
Uruguay			
	Bovine meat	0.4	Bosilevac *et al*. (2007)
	Eggs	0.005	Betancor *et al*. (2010)
Venezuela			
	Chicken meat and giblets	23.2, 91	Rengel and Mendoza (1984); Boscán *et al*. (2005)
	Bovine meat	3.5-45	Narváez *et al*. (2005); Narváez-Bravo *et al*. (2013b); Rodriguez-Roque *et al*. (2018)
	Seafood	2.0, 38.9	Morillo *et al*. (2007); Gómez-Gamboa *et al*. (2012)
	Texturized soybean meal	45	Narváez *et al*. (2005)

[a] Horse and sheep meat.
[b] Poultry, pork, beef, veal, lamb, and turkey meat.

TABLE 2. DISTRIBUTION AND DIVERSITY OF NONTYPHOIDAL *SALMONELLA* SEROVARS REPORTED FROM FOOD PRODUCTS IN LATIN AMERICA

Country	Analyzed foods	Serotype	Percentage (%) *	References
Argentina				
	Chicken meat	Enteritidis	59.3	Favier *et al*. (2013)
	Chicken giblets	Schwarzengrund	81.2	Procura *et al*. (2019)
	Bovine meat	Newport	40.7	Curi de Montbrun *et al*., (1972)
		Typhimurium	22.2	Curi de Montbrun *et al*. (1972)
	Pork meat	Typhimurium	100	Colello *et al*. (2018)
	Pork sausage	Anatum	22.2	Favier *et al*. (2013)
	Crushed bone meal	Anatum	22.7	Harvey and Price (1978)
Brazil				
	Chicken meat and derived food	Enteritidis	25-100	Santos *et al*. (2000); Baú *et al*. (2001); Hernandez *et al*. (2005); Cortez *et al*. (2006); Tessari *et al*. (2008); Asensi *et al*. (2009); Medeiros *et al*. (2011); Palmeira *et al*. (2016); Ristori *et al*. (2017)
		Infantis	35.4	da Cunha-Neto *et al*. (2018)
		Abony	25.8	da Cunha-Neto *et al*. (2018)
		Schwarzengrund	85.7	Tejada *et al*. (2016)
		Albany	100	Luiz *et al*. (2004)
		Typhimurium	42.9	Perin *et al*. (2019)
		Heidelberg	38.8	Perin *et al*.,(2019)
		Kentucky	26.7	Cortez *et al*. (2006)
	Chicken meat and giblets	Enteritidis	38.48	Minharro *et al*. (2015)
	Pork meat	Typhimurium	28.6-50.7	Tessmann *et al*. (2008); Seixas *et al*. (2009); Kich *et al*. (2011); Silva *et al*. (2012); Cabral *et al*. (2017); Paim *et al*. (2019)

		Derby	23.1-35.2	Seixas *et al*. (2009); Silva *et al*. (2012); Paim *et al*. (2019)
		Panama	24.1, 28.5	Kich *et al*. (2011); Silva *et al*. (2012)
		Infantis	37.5-100	Tessmann *et al*. (2008)
	Bovine meat	Livingstone	100	Loiko *et al*. (2016)
		Derby	47.1	Cossi *et al*. (2014)
		Dublin	41.2	Cossi *et al*. (2014)
	Pork sausages	Typhimurium	47.4, 100	Spricigo *et al*. (2008); Mürmann *et al*. (2011); Ristori *et al*. (2017); Werlang *et al*. (2019)
		Bredeney	33.3	Castagna *et al*. (2005)
		Saintpaul	20.8	Castagna *et al*. (2005)
	Eggs	Senftenberg	100	Galvão *et al*. (2018)
		Enteritidis	82.6, 100	Kottwitz *et al*. (2013)
		Mbandaka	50	Freitas *et al*. (2014)
		6,7: z10:-	33.3	Freitas *et al*. (2014)
	Seafood (crabs)	Senftenberg	71.4	Vieira *et al*. (2004)
		Poona	28.6	Vieira *et al*. (2004)
		Panama	100	Santos *et al*. (2019)
	Vegetables	Javiana	33.3	Takayanagui *et al*. (2001)
		Typhimurium	75	Sant'Ana *et al*. (2011)
		O:47:z4,z23:-	25	Sant'Ana *et al*. (2011)
	Orange juice	Cholerasuis	100	Ruschel *et al*. (2001)
	Peanuts	Miami	50	Nascimento *et al*. (2018)
	Pig feed	Senftenberg	100	Silva *et al*. (2006)
Chile				
	Chicken meat	Infantis	96.7	Lapierre *et al*. (2020)
		Enteritidis	70, 100	Alexandre *et al*. (2000); Ulloa *et al*. (2010)

	Chicken giblets	Enteritidis	38, 100	Alexandre *et al*. (2000); Ulloa *et al*. (2010)
	Eggs	Enteritidis	100	Alexandre *et al*. (2000)
Colombia				
	Chicken meat	Uganda	33.3	Espinal *et al*. (2006)
		Anatum	25	Espinal *et al*. (2006)
	Pork meat	Derby	22.2, 40	Rondón-Barragán *et al*. (2015)
		Typhimurium	40	Rondón-Barragán *et al*. (2015)
		Muenster	44.4	Rondón-Barragán *et al*. (2015)
		Hvittingfoss	22.2	Rondón-Barragán *et al*. (2015)
		Uganda	33.3	Espinal *et al*. (2006)
		Anatum	33.3	Espinal *et al*. (2006)
	Bovine meat	Anatum	38.9	Espinal *et al*. (2006)
		Uganda	33.3	Espinal *et al*. (2006)
		Brandenburg	33.3	Espinal *et al*. (2006)
	Cold meats	Uganda	22.2	Espinal *et al*. (2006)
		Gaminara	22.2	Espinal *et al*. (2006)
	Eggs	Enteritidis	100	Mogollón *et al*. (2016)
	Egg arepa	Derby	100	Espinal *et al*. (2006)
	Drinking water	Rubislaw	100	Espinal *et al*. (2006)
Costa Rica				
	Meat and bone meal	Give	40	Molina *et al*. (2015)
	Feedstuff	Havana	20.6	Molina *et al*. (2015)
		Heidelberg	100	Molina *et al*. (2015)
Cuba				
	Meat	Agona	21.1	Puig *et al*. (2011)
	Dairy products	Infantis	100	Puig *et al*. (2011)

	Processed food	Enteritidis	40	Puig *et al*. (2011)
		London	40	Puig *et al*. (2011)
	Egg-based foods	Enteritidis	62.2	Puig *et al*. (2011)
	Spices	Typhimurium	100	Puig *et al*. (2011)
Ecuador				
	Chicken meat and skin	Infantis	100	Vinueza-Burgos *et al*. (2019); Mejia *et al*. (2020)
	Chicken skin	Infantis	100	Villagómez (2015)
	Eggs	Enteritidis	100	Sánchez (2013); Solano (2016)
	Poultry feed	Infantis	100	Salazar *et al*. (2019)
Mexico				
	Chicken meat	Gallinarum	33.1	Villalpando-Guzmán *et al*. (2017)
		Pullorum	22.3	Villalpando-Guzmán *et al*. (2017)
	Chicken giblets	Typhimurium	100	Talavera *et al*. (2011)
	Pork meat	Newport	36.6	Villalpando-Guzmán *et al*. (2017)
		Anatum	31.7	Villalpando-Guzmán *et al*. (2017)
		Typhimurium	21.8	Villalpando-Guzmán *et al*. (2017)
	Bovine meat	Typhimurium	28.8-48	Varela-Guerrero *et al*. (2013); Martínez-Chávez *et al*. (2015); Villalpando-Guzmán *et al*. (2017)
		Anatum	40.7	Villalpando-Guzmán *et al*. (2017)
		Meleagridis	27.9	Zaidi *et al*. (2006)
		Give	24.4	Perez-Montaño *et al*. (2012)
	Pork sausage	Derby	26	Escartin *et al*. (1999)
	Fruits	Agona	100	Mba-Jonas *et al*. (2018)
		Typhimurium	100	Gallegos-Robles *et al*. (2008)
	Fruit juice	Agona	46.2	Castillo *et al*. (2006)
		Typhimurium	30.8	Castillo *et al*. (2006)
		Anatum	23.1	Castillo *et al*. (2006)

	Vegetables juice	Typhimurium	75	Gómez-Aldapa *et al*. (2014)
		Enteritidis	25	Gómez-Aldapa *et al*. (2014)
	Vegetables	Typhimurium	23.9-80	Gallegos-Robles *et al*. (2008); Quiroz-Santiago *et al*. (2009); Rangel-Vargas *et al*. (2015); Gutiérrez-Alcántara *et al*. (2016)
		Enteritidis	20-100	Estrada-Garcia *et al*. (2004); Gallegos-Robles *et al*. (2008); Gómez-Aldapa *et al*. (2014); Rangel-Vargas *et al*. (2015)
	Chocolate	Agona	100	Torres-Vitela *et al*. (1995)
		Derby	100	
	Chili sauce	Enteritidis	100	Estrada-Garcia *et al*. (2004)
Paraguay				
	Chicken meat	Mbandaka	25	Weiler *et al*. (2017)
		Albany	25	
Peru				
	Pork meat	Derby	100	Salvatierra *et al*. (2015)
Uruguay				
	Bovine meat	Newport	100	Bosilevac *et al*. (2007)
	Eggs	Derby	67	Betancor *et al*. (2010)
Venezuela				
	Chicken meat and giblets	Anatum	32	Rengel and Mendoza (1984)
	Chicken giblets	Heidelberg	31.2, 32	Boscán *et al*. (2005); Boscán-Duque *et al*. (2007)

* Only values greater than 20% are included.

Supplementary Material (Chapter 1)

Table S1. Databases and search terms (Via Google)

#	Date of search	Search time	Databse	Search terms	Number of citations
#1	July 19, 2020	12:53:00	Pubmed	"*Salmonella*" AND ((food OR bread OR cooking OR drink OR feed OR foodstuff OR meal OR meat OR snack) AND (Argentina OR Bolivia OR Brazil OR Chile OR Colombia OR "Costa Rica" OR Cuba OR "Dominican Republic" OR Ecuador OR "El Salvador" OR Guatemala OR Haiti OR Honduras OR Mexico OR Nicaragua OR Panama OR Paraguay OR Peru OR "Puerto Rico" OR Uruguay OR Venezuela))	1251
#2	July 19, 2020	13:03:00	SciELO	#1	247
#3	July 19, 2020	13:20:00	Scopus	"*Salmonella*" AND ((food OR bread OR cooking OR drink OR feed OR foodstuff OR meal OR meat OR snack) AND (Argentina OR Bolivia OR Brazil OR Chile OR Colombia OR "Costa Rica" OR Cuba OR "Dominican Republic" OR Ecuador OR "El Salvador" OR Guatemala OR Haiti))	598
#4	July 19, 2020	13:22:00	Scopus	"*Salmonella*" AND ((food OR bread OR cooking OR drink OR feed OR foodstuff OR meal OR meat OR snack) AND (Honduras OR Mexico OR Nicaragua OR Panama OR Paraguay OR Peru OR "Puerto Rico" OR Uruguay OR Venezuela))	366
#5	July 19, 2020	13:29:00	Springer	#1	82
				TOTAL	2544

Table S2. Food source, serotype, prevalence, and detection method(s) of nontyphoidal *Salmonella* in various food products from Latin America

Country	Analyzed food	Sampling date / period	Isolated nontyphoidal *Salmonella*	Sample size (*n*)	Prevalence (%)	Detection method		Reference
						Classical Microbiology protocol	Molecular method(s)	
Argentina	Chicken carcasses	2000-07 to 2001-07	*Salmonella* spp.	60	20	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Jiménez *et al*., 2002)
Argentina	Chicken meat	2005 to 2011	*S.* Enteritidis *S.* Montevideo	115	14.8	Bacteriological Analytical Manual (US-FDA)	PCR and PFGE	(Favier *et al*., 2013)
	Pork sausages		*S.* Anatum	90	6.6			
	Chicken giblets		*S.* Montevideo	62	3.2			
	Liquid eggs		*S.* Typhimurium	60	3.3			
Argentina	Hen feed	2011-08 to 2012-04	*Salmonella* spp.	304	4.6	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Soria *et al*., 2017)
Argentina	Pig carcasses, pork meat, minced pork	2012 to 2015	*S.* Typhimurium	764	4.5	Bacteriological Analytical Manual (US-FDA)	PCR-*inv*A gene	(Colello *et al*., 2018)
Argentina	Chicken livers	2015-10 to 2016-05	*S.* Enteritidis *S.* Typhimurium *S.* Schwarzengrund	666	4.8	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Procura *et al*., 2017)
Argentina	Raw ground beef	2015-12 to 2017-01	*S.* Enteritidis *S.* Senftenberg *S.* Typhimurium	44	15.9	International guidelines ISO 6579	None	(Barril *et al*., 2019)
Argentina	Bovine meat	NA	*S.* Newport *S.* Typhimurium *S.* Cholerasuis	100	34	Pre-enrichment, selective enrichment, culture on	None	(Curi de Montbrun *et al*., 1972)

			S. Anatum			selective media, reactivity with *Salmonella* spp. antiserum		
Argentina	Crushed bone meal	NA	*S.* Anatum *S.* Senftenberg *S.* Kentucky *S.* Meleagridis *S.* Montevideo *S.* Derby *S.* Minnesota *S.* Oranienburg *S.* Panama *S.* Give *S.* Newport *S.* Typhimurium *S.* Bovismorbificans *S.* Cubana *S.* Infantis *S.* Sandiego *S.* Bredeney *S.* Eimsbuettel *S.* Cerro *S.* Kaminara *S.* Java *S.* Jukestown *S.* Lexington *S.* Chester *S.* Corvalis *S.* Edinburgh *S.* Glostrup *S.* Good *S.* Grumpensis *S.* Hartfield	2801	1.3	Pre-enrichment, selective enrichment, culture on selective media, reactivity with *Salmonella* spp. antiserum	None	(Harvey and Price, 1978)

			S. Newlands *S.* Saintpaul					
Brazil	Horse meat	1980 to 1982	S. Saintpaul S. Agona S. Typhimurium S. Kaapstad S. Chester S. Sandiego S. Schleissheim S. Haifa S. Kimuenza S. Derby S. Tudu S. Reading S. Azteca S. Aynde S. Ball S. Bochum S. Bredeney S. Fyris S. Infantis S. Oranienburg S. Concord S. Colindale S. Eschweiler S. Nigeria S. Papuana S. Bonn S. Inganda S. Montevideo S. Edinburg S. Grampian	19 238	3.4	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Hofer *et al.*, 2000)

			S. Kotte S. Norwich S. Oslo S. Newport S. Bardo S. Tshiongwe S. Muenchen S. Albany S. Sunnycove S. Virginia S. Amherstiana S. Bovismorbificans S. Kentucky S. Panama S. Eastbourne S. Ndolo S. Portland S. Claibornei S. Jaffna S. Newlands S. Anatum S. Give S. Meleagridis S. Harrisonburg S. Nyborg S. Florian S. Langensalza S. Minneapolis S. Newbrunswick S. Ohlstedt S. Vejle S. Fann					

			S. Rubislaw S. Poona S. Leiden S. Bristol S. Havana S. Roodepoort S. Washington S. Carrau S. Horsham S. Malakal S. Cerro S. Langenhorn S. Minnesota S. Ruiru S. Baguida S. Adelaide					
Brazil	Lettuce, fennel	1995-08 to 1997-07	*S.* Abaetetuba *S.* Enteritidis *S.* Schwarzengrund	NA	3.1	Not indicated	None	(Takayanagui *et al*., 2000)
Brazil	Unpasteurized orange juice	1996-03 to 1998-01	*S.* Cholerasuis	52	1.92	Compendium of methods for the microbiological examination of foods, APHA	None	(Ruschel *et al*., 2001)
Brazil	Chicken products (chest, back, thighs, wings, heart, liver, gizzard, and eggs)	1997-05 to 1998-04	*S.* Enteritidis *S.* Anatum *S. enterica* subsp. *enterica* serovar 3,10:e,h:-	124	10.48	Bacteriological Analytical Manual (US-FDA)	None	(Baú *et al*., 2001)
Brazil	Lettuce, chicory, arugula	1997-07 to 1998-07	*S.* Javiana *S.* Oranienburg *S.* Anatum	172	9	Pre-enrichment, selective enrichment, culture on	None	(Takayanagui *et al*., 2001)

			S. Emek *S.* Infantis S. Morehead *S.* Panama *S.* Typhimurium *S. enterica* subsp. *diarizonae* 6:i:z *S.* Agona			selective media, biochemical characterization		
Brazil	Chicken carcasses	1998-03 to 1998-05	*Salmonella* spp.	60	50	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Tirolli and Da Costa, 2006)
Brazil	Chicken carcasses	1998 to 2002	*Salmonella* spp.	45	13.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Carvalho and Cortez, 2005)
	Mechanically deboned meat			15	25			
	Chicken sausages			25	16			
	Chicken chest			20	30			
	Chicken leg, and thigh			15	13.3			
Brazil	Minced pork	1999 to 2000	*Salmonella* spp.	30	93.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Borowsky *et al*., 2007)
Brazil	Crabs (*Ucides cordatus*)	2003-02 to 2003-05	*S.* Senftenberg *S.* Poona	90	15.2	Compendium of methods for the microbiological examination of foods, APHA	None	(Vieira *et al*., 2004)
Brazil	Eggs (pooled yolks)	2003-08 to 2006-12	S. Enteritidis	50	6	AOAC Protocol	None	(Kottwitz *et al*., 2013)
	Eggs (rinses of eggshells)		S. Enteritidis S. Heidelberg	50	46			

			S. Mbandaka S. Anatum					
Brazil	Lettuce, watercress, spinach, arugula, chicories, broccoli, cabbage, kale, mustard leaves, acelga	2004-03 to 2004-07	*Salmonella* spp.	133	3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Fröder *et al*., 2007)
Brazil	Chicken carcasses	2004-09 to 2006-07	S. Enteritidis S. Infantis S. Typhimurium S. Heidelberg S. Mbandaka S. Agona S. Rissen S. Give S. Panama S. Schwarzengrund S. Senftenberg S. Minnesota S. Saintpaul S. Ohio S. Lexington S. Newport S. Gaminara S. Rubislaw *Salmonella* spp.	2679	2.7	Bacteriological Analytical Manual (US-FDA)	None	(Medeiros *et al*., 2011)

Brazil	Fresh pork sausages	2005-03 to 2005-08	*S.* Typhimurium	125	12.8	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Spricigo *et al*., 2008)
Brazil	Fresh pork sausages	2005-09 to 2006-04	*S.* Derby *S.* Schwarzengrund *S.* Typhimurium	200	27	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization, reactivity with *Salmonella* spp. antiserum	None	(Spricigo, Matsumoto, Espíndola and Ferraz, 2008)
Brazil	Cooked ham	2005-09 to 2005-12	*Salmonella* spp.	40	30	Compendium of methods for the microbiological examination of foods, APHA	None	(Fai *et al*., 2011)
Brazil	Chicken meat	2006-03 to 3006-08	*Salmonella* spp.	50	8	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Rall *et al*., 2009)
Brazil	Pork chuleta	2006-06 to 2006-08	*S.* Infantis *S.* Typhimurium *S.* Panama	15	80	Compendium of methods for the microbiological examination of foods, APHA	None	(Tessmann *et al*., 2008)
	Pork leg		*S.* Typhimurium *S.* Infantis *S.* Derby	15				
	Pork rib		*S.* Infantis	15				
Brazil	Chicken carcasses	2006-07 to 2007-06	*S.* Enteritidis	116	2.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Tessari *et al*., 2008)
Brazil	Sheep meat	2006-09 to 2007-06	*Salmonella* spp.	26	30.8	ICMSF	None	(Fernandes *et al*., 2009)

Brazil	Poultry carcasses	2007-01 to 2013-04	*Salmonella* spp.	340	19.41	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Bersot, Viana *et al*., 2019)
Brazil	Chicken feet	2009-05 to 2009-07	*S.* Schwarzengrund *S.* Anatum *S.* Corvallis	80	68 (before scalding) and 5.6 (after processing)	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Santos *et al*., 2011)
Brazil	Charqui (dehydrated meat)	2009-06 to 2019-02	*Salmonella* spp.	25	28	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Abrantes *et al*., 2014)
Brazil	Chicken carcasses	2010-03 to 2010-09	*Salmonella* spp.	30	3.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Cossi *et al*., 2012)
Brazil	Chicken carcasses, heart, and liver	2010-08 to 2011-06	S. Agona S. Anatum S. Enteritidis S. Infantis S. Mbandaka S. Minnesota S. Orion S. Panama S. Schwarzengrund	1500	18.33	MAPA protocol (BRASIL, 2003a)	None	(Minharro *et al*., 2015)
Brazil	Cattle carcasses	2010-09 to 2012-02	S. Livingstone	108	0.93	International guidelines ISO 6579	PCR-*inv*A gene	(Loiko *et al*., 2016)
Brazil	Pig carcasses	2011-08 to 2012-09	*Salmonella* spp.	1150	8.7	VIDAS® SLM system (with confirmation)	None	(Corbellini *et al*., 2016)

Brazil	Swine carcasses	2011-10 to 2011-11 and 2012-02 to 2012-03	*Salmonella* spp.	240	29.17	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Silva *et al*., 2018)
Brazil	Chicken sausages	2011-11 to 2012-06	*Salmonella* spp.	29	20	Conventional method and system mini-Vidas®	None	(Cabral *et al*., 2014)
	Pork sausages			51	29			
Brazil	Gills of river salmon	2012 to 2015	*S.* Panama	567	6.87	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	MLST	(Santos *et al*., 2019)
Brazil	Chicken carcasses	2014-01 to 2014-09	*Salmonella* spp.	277	24.5	International guidelines ISO 6579	PFGE	(Dias *et al*., 2016)
Brazil	Chicken carcasses	2014-01 to 2015-05	*S.* Abony *S.* Agona *S.* Anatum *S.* Infantis *S.* Schwarzengrund *Salmonella* (O:4,5) *Salmonella* (O:6,7)	850	3.7	International guidelines ISO 6579	Multiplex-qPCR	(Cunha-Neto *et al*., 2018)
Brazil	Peanuts (during processing)	2014-01 to 2015-07	*S.* Miami *S.* Muenster *S.* Javiana *S.* Oranienburg *S.* Glostrup	414	2.2	International guidelines ISO 6579	None	(Nascimento *et al*., 2018)
Brazil	Custard apple pulp	2014-03 to 2014-08	*S. enterica* *Salmonella* spp.	200	1.5	International guidelines ISO 6579	PFGE	(Rezende *et al*., 2016)

Brazil	Swine carcasses	2014-04 to 2014-08	*Salmonella* spp.	258	7.75	AOAC Protocol	No	(Neitzke *et al*., 2017)
Brazil	Swine carcasses	2014-05 to 2015-08	*S.* Typhimurium *S.* Abony *S.* Give *S. enterica* subsp. *enterica* O:4,5 *S.* Heidelberg	344	10.5	Bacteriological Analytical Manual (US-FDA)	None	(Cabral *et al*., 2017)
Brazil	Fresh cheese	2015	*Salmonella* spp.	350	25.9	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Carvalho *et al*., 2019)
	Handmade jelly				20			
	Cucumber				24.7			
Brazil	Pork sausages	2015-03 to 2015-07	*Salmonella* spp.	46	28.3	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Cavalin *et al*., 2018)
Brazil	Wings	2015-08 to 2016-02	*S.* Typhimurium *S.* Heidelberg *S.* Ndolo *S.* Minnesota *S. enterica* subsp. *enterica* (O:4,5) *S.* Thompson *S.* Schwarzengrund *S. enterica* subsp. *enterica* (O:3,10:e,h) *S.* Abony	71	39.4	International guidelines ISO 6579	PCR-*inv*A gene and PFGE	(Perin *et al*., 2019)
	Breast			103	32			
	Leg			72	23.6			
	Fried chicken			54	31.5			
Brazil	Fresh cheese	2015-10 to 2016-01	*Salmonella* spp.	50	40	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Souza *et al*., 2017)

Brazil	Sliced collard green	2015-12 to 2017-07	*Salmonella* spp.	13	23.1	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Cruz *et al*., 2019)
	Sliced cabbage			4	25			
Brazil	Chicken carcasses	2016-03 to 2016-09	*S.* Senftenberg S. Mbandaka S. Schwarzengrund S. Cerro S. Ohio *S.* Minnesota S. Tennessee	60	26.7	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Baptista *et al*., 2018)
Brazil	White cabbage	2016-06 to 2016-08	*Salmonella* spp.	20	5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Beltrão *et al*., 2017)
Brazil	Minced beef	2016-06 to 2017-08	*Salmonella* spp.	15	27	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Monteiro *et al*., 2018)
Brazil	Mozzarella cheese	2016-08 to 2016-10	*Salmonella* spp.	10	20	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Reges *et al*., 2017)
Brazil	Turkey ham	2017-08 to 2017-09	*Salmonella* spp.	20	10	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Freire *et al*., 2019)
Brazil	Black pepper	2018-02 to 2018-07	*Salmonella* spp.	9	67	Bacteriological Analytical Manual (US-FDA)	None	(Costa *et al*., 2020)
Brazil	Chicken meat	5-months period	*S.* Albany	185	3.24	Pre-enrichment, selective enrichment, culture on	None	(Luiz *et al*., 2004)

						selective media, biochemical characterization		
Brazil	Feed ingredients (bone meal, fish's flour, meat meal, blood flour, dry cheese whey base, whey, soybean meal, wafer bran, toasted soy, wheat flour)	NA	*S.* Heidelberg *S.* Infantis S. Montevideo S. Mbandaka S. Emek S. Newlands S. Anatum S. Mokola S. Muenster S. Senftenberg S. Cerro	136	19.85	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Albuquerque *et al*., 1999)
	Poultry feed			38	2.63			
	Pig feed			5	20			
Brazil	Frozen chicken carcasses	NA	S. Enteritidis S. Agona S. Poona S. Hadar S. Mbandaka S. Anatum S. Havana S. Montevideo S. Ouakam S. Schwarzengrund S. I 4,5,12: -	150	32	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Santos *et al*., 2000)

Brazil	Pig carcasses	NA	*Salmonella* spp.	120	11.7	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Lima *et al*., 2004)
Brazil	Pork sausage meat	NA	*S.* Bredeney *S.* Typhimurium *S.* Saintpaul *S.* Panama *S.* Enteritidis *S.* Mbandaka *S.* Minnesota	38	66	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Castagna *et al*., 2005)
Brazil	Chicken legs	NA	*S.* Enteritidis *S.* Heidelberg	143	23.8	International guidelines ISO 6579	None	(Hernandez *et al*., 2005)
	Chicken breasts		*S.* Enteritidis *S.* Thompson *S.* Munchen	121	11.0			
Brazil	Pig feed	NA	*S.* Senftenberg	26	7.7	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Silva *et al*., 2006)
Brazil	Pequi pulp	NA	*Salmonella* spp.	10	33.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Ferreira & Junqueira, 2007)
Brazil	Chicken carcasses	NA	*S.* Enteritidis *S. enterica* subsp. *houtenae* *S.* Mbandaka *S.* Saintpaul *Salmonella* spp.	30	47	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Asensi *et al*., 2009)
Brazil	Pig carcasses	NA	*S.* Typhimurium *S.* Derby	6	4.2	Pre-enrichment, selective enrichment, culture on	None	(Seixas *et al*., 2009)

			S. Heidelberg			selective media, biochemical characterization		
Brazil	Pig feed	NA	*S.* Typhimurium *S.* Agona	3	66.7	Not indicated	RAPD-PCR (random amplified polymorphism DNA-PCR)	(Melo *et al*., 2011)
Brazil	Wild chicory	NA	*S.* Madelia *S.* London	13	1.2	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Oliveira *et al*., 2011)
Brazil	Swine sausages	NA	*Salmonella* spp.	91	53	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Lima *et al*., , 2011)
Brazil	Minimally processed lettuce	NA	*S.* Typhimurium	512	0.4	International guidelines ISO 6579	None	(Sant'Ana *et al*., 2011)
	Minimally processed arugula		*Salmonella enterica* subsp. *enterica* O:47:z4,z23:-					
	Minimally processed organic lettuce and mix of escarole and chicory		*S.* Typhimurium					
Brazil	Pre-chilled pork carcasses	NA	*S.* Typhimurium *S.* Panama *S.* Derby	98	24	Pre-enrichment, selective enrichment, culture on selective media, further examination	PFGE	(Kich *et al*., 2011)
	Post-chilled pork carcasses		*S.* Typhimurium *S.* Panama	260	24			

			S. Derby *S.* Mbandaka *S.* Infantis					
Brazil	Pork sausages	NA	*S.* Typhimurium	NA	24.4	Not indicated	None	(Mürmann *et al*., 2011)
Brazil	Pig carcasses	NA	*S.* Typhimurium *S.* Derby *S.* Panama *S.* Brandenburg *S.* Infantis	109	14.7	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PFGE	(Silva *et al*., 2012)
Brazil	Raw eggs from Recife	NA	*Salmonella* spp.	180	25	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Evêncio-Luz *et al*., 2012)
	Raw eggs from Salvador			240	11.25			
	Cheese from Recife			65	7.8			
	Cheese from Salvador			75	12.7			
Brazil	Cold sausages	NA	*Salmonella* spp.	51	11	Conventional method and system mini-Vidas®	None	(Benetti *et al*., 2013)
Brazil	Mechanically separated meat	NA	*Salmonella* spp.	390	11.02	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Yamaguchi *et al*., 2013)
	Chicken carcasses			82	3.66			
	Milk powder			255	1.57			
	Butter			579	0.35			
Brazil	Bovine carcasses	NA	*S.* Derby *S.* Dublin *S.* Infantis *S.* Give S. salamae subsp. salamae	836	0.7	International guidelines ISO 6579	PCR-*omp*C gene and PFGE	(Cossi *et al*., 2014)

Brazil	Pig feed	NA	*S.* Typhimurium *S.* Agona *S.* Infantis *S.* Minnesota *S.* Panama	3	66.7	International guidelines ISO 6579	RAPD-PCR (random amplified polymorphism DNA-PCR)	(Moura *et al*., 2014)
	Pig carcasses			90	25.5			
Brazil	Eggs	NA	*S.* Mbandaka *S. enterica* subsp. *enterica* 6,7: z10:- *S.* Braenderup	340	1.47	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Freitas *et al*., 2014)
Brazil	Sliced mozzarella cheese	NA	*Salmonella* spp.	20	5	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Marinheiro *et al*., 2015)
Brazil	Chicken meat	NA	*S.* Schwarzengrund *S.* Mbandaka	200	4	Pre-enrichment, selective enrichment, culture on selective media, further examination	PCR and PFGE	(Tejada *et al*., 2016)
Brazil	Ground beef	NA	*Salmonella* spp.	20	60	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Volcão *et al*., 2016)
Brazil	Pork sausages	NA	*S.* Typhimurium *S.* Derby *S.* Infantis *S.* Brandenburg *S.* Rissen *S.* I 4,[5],12:i:- *S.* Ohio	32	62.5	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Ristori *et al*., 2017)
	Chicken legs		*S.* Anatum *S.* Newport *S.* Brandenburg *S.* Enteritidis	32	37.5			

			S. enterica subsp. *diarizonae* 61:c:z35 *S. enterica* subsp. *diarizonae* 61:c:- *S.* Schwarzengrund *S.* I 4,[5],12:i:-					
Brazil	Fresh cheese	NA	*Salmonella* spp.	100	2	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Queiroz *et al*., 2018)
Brazil	Eggs (eggshell)	NA	*S.* Senftenberg	194	1.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Galvão *et al*., 2018)
Brazil	Beef carcasses	NA	*S.* Typhimurium	270	2.6	ISO 2002, with modifications	PCR-*inv*A gene and qPCR	(Bier *et al*., 2018)
Brazil	Lettuce	NA	*Salmonella* spp.	200	1	Pre-enrichment, selective enrichment, culture on selective media, further examination	qPCR	(Maffei *et al*., 2019)
Brazil	Salami	NA	*S.* Typhimurium	90	4.4	ISO 6785/2007	None	(Werlang *et al*., 2019)
Brazil	Pig barn feed	2007-01 to 2013-03	*S.* Typhimurium *S.* Mbandaka *S.* Panama *S.* Derby *S.* Agona *S.* Give *S.* Worthington *S.* Meleagridis *S.* Poona	216	9.3	USDA Microbiology Laboratory Guidebook (Isolation and Identification of *Salmonella* from Meat, Poultry and Egg Products)	PFGE	(Bersot, Cavicchioli *et al*., 2019)
	Pig carcasses			130	0.8			

Brazil	Pork cuts	NA	*Salmonella* spp.	40	10	International guidelines ISO 6579	PCR-*inv*A and -*omp*C genes, and PFGE	(Viana *et al*., 2019)
Brazil	Pig carcasses (after bleeding)	NA	S. Typhimurium S. Derby S. Brandenburg S. Panama	50	16	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PFGE and WGS-MLST	(Paim *et al*., 2019)
	Pig carcasses (before chilling)		S. Derby S. O:4,5 S. Typhimurium S. Infantis	50	8			
Chile	Eggs	1998 to 1999	*S.* Enteritidis	1081	0.09	Bacteriological Analytical Manual (US-FDA)	None	(Alexandre *et al*., 2000)
	Chicken meat		*S.* Enteritidis *S.* Heidelberg *S.* Hadar *S.* Cerro *S.* Infantis *S.* Anatum *S.* Dublin	1154	8.31			
	Chicken giblets			370	12.97			
Chile	Broiler meat	2016	*S.* Infantis *S.* Enteritidis	361	24.8	VIDAS *Salmonella* (Biomeriux®) International guidelines ISO 6579	PCR target genes amplification	(Lapierre *et al*., 2020)
Chile	Chicken carcasses	NA	*S.* Enteritidis	280	1.8	Not indicated	None	(Ulloa *et al*., 2010)
	Chicken giblets			280	0.4			
Colombia	Beef	2002-01 to 2003-03	*S.* Anatum *S.* Brandenburg *S.* Gaminara *S.* Isangi	1300	40.5	Bacteriological Analytical Manual (US-FDA)	PCR-*inv*A gene	(Espinal *et al*., 2006)
	Sausages				17.6			
	Chicken meat				16.2			
	Cheese				12.2			

	Pork meat Egg arepa Drinking water Giblets		*S.* Muenchen *S.* Newport *S.* Rubislaw *S.* Sandiego *S.* Typhimurium *S.* Uganda		8.1 2.7 1.4 1.4			
Colombia	Raw milk	2008-02 to 2008-06	*Salmonella* spp.	68 (summer) 111 (winter)	4.4 1.8	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Martinez & Gomez, 2013)
Colombia	Poultry meat	2009-03 to 2009-10	*S.* Heidelberg *S.* Enteritidis *S.* Typhimurium *S.* Muenster *S.* Lome	200	26	Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) Protocol	None	(Donado-Godoy *et al.*, 2015)
Colombia	Chicken meat	2010-10 to 2011-04	*Salmonella* spp.	1003	27	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Donado-Godoy *et al.*, 2012)
Colombia	Artisanal cheese	2013-01 to 2013-05	*Salmonella* spp.	27	62.9	Not indicated	qPCR	(Soto-Varela *et al.*, 2018)
Colombia	Poultry carcasses	2014-02 to 2014-05	*S.* Hvittingfoss *S.* Muenster *S.* Typhimurium *S.* Newport *S.* Heidelberg *S.* Braenderup *S.* Kalina *S.* Bovismorbificans *S.* Budapest *S.* Manhattan	270	17.41	International guidelines ISO 6579	None	(Rodriguez *et al.*, 2015)

			S. Othmarschen *S.* Schwarzengrund *S.* Skansen					
Colombia	Eggs (surface)	2014-01 to 2014-08	*S.* Enteritidis	341	2.93	International guidelines ISO 6579	None	(Mogollón *et al*. 2016)
Colombia	Chicken carcasses	2015-04 to 2015-11	*Salmonella* spp.	520	12.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	LAMP (3M MDS)	(Ramírez-Hernández *et al*., 2017)
Colombia	Chicken meat	2016-05 to 2016-11	*Salmonella* spp.	18	83.3	International guidelines ISO 6579	SDS-PAGE and Western blot	(Quintana-Ospina *et al*., 2018)
	Eggs (surface)			18	22.2			
Colombia	Pork meat	NA	*S.* Derby *S.* Typhimurium *S.* Javiana *S.* Muenster	421	3.32	International guidelines ISO 6579	None	(Rondón-Barragán *et al*., 2015)
	Pork carcasses		*S.* Derby *S.* Muenster *S.* Hvittingfoss *S.* Kattbus		16			
Colombia	Ready to eat rice	NA	*Salmonella* spp.	303	0.3	Not indicated	qPCR	(Forero *et al*., 2017)
	Ready to eat chicken			80	2.5			
Costa Rica	Eggshell	1993-07 to 1994-03	*Salmonella* spp.	150	25.3	Bacteriological Analytical Manual (US-FDA)	None	(Arias *et al*., 1996)
	Egg contents (albumen and yolk)				18.7			
Costa Rica	Meat and bone meal (feedstuffs)	2009 to 2014	*S.* Anatum *S.* Brandenburg *S.* Havana	86	26.74	ISO 17025 accredited modified version of the U.S. Food and Drug Administration	None	(Molina *et al*., 2015)

			S. Infantis *S.* Manchester *S.* Mbandaka *S.* Montevideo *S.* Soerenga *S.* Muenster *S.* Yoruba *S.* Rissen *S.* Give			Bacteriological Analytical Manual (BAM) method (FDA)		
	Poultry compound feed		*S.* Amsterdam *S.* Berta *S.* Alachua *S.* Mbandaka *S.* Anatum *S.* Senftenberg *S.* Yoruba *S.* Rissen *S.* Schwarzengrund *S.* Soerenga *S.* Havana	1420	5.35			
	Pet food		*S.* Heidelberg	89	3.37			
Costa Rica	Retail beef cuts	2012-08 to 2013-08	*Salmonella* spp.	279	3.6	Pre-enrichment, selective enrichment, culture on selective media, further examination	PCR target genes amplification	(Chaves and Brashears, 2015)
Costa Rica	Puppy food	2012 to 2018	*Salmonella* spp.	68	1.47	ISO 17025	None	(Leiva *et al*., 2019)
	Adult dog food			158	1.26			
	Cat food			25	4			
Costa Rica	Chicken giblets	NA	*Salmonella* spp.	100	15	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Reuben *et al*., 2004)

Costa Rica	Tilapia	NA	*Salmonella* spp.	50	2	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Morales *et al*., 2004)
Cuba	Artisan fresh cheese	2011	*Salmonella* spp.	73	19	International guidelines ISO 6579	None	(Martínez *et al*., 2013)
Ecuador	Frozen shrimp	1989 to 1990	*Salmonella* spp.	28	7.1	Not indicated	None	(Gecan *et al*., 1994)
Ecuador	Beef	2010-06 to 2010-07	*Salmonella* spp.	120	66.7	Norma Técnica Ecuatoriana NTE INEN 1529 -15:2009	None	(Loayza, 2011)
Ecuador	Fresh cheese	2011-08	*Salmonella* spp.	51	13.7	Norma Técnica Ecuatoriana NTE INEN 1529 -15:2009	None	(Plaza-Ibarra and Morales, 2001)
Ecuador	Poultry, pork, beef, veal, lamb, turkey meat	2015 to 2016	*S.* Infantis *S.* Typhimurium *S.* Dublin *S.* Gallinarum *S.* Choleraesuis *S.* Enteritidis *S.* Javiana *S.* Heidelberg *S.* Brandenburg *S.* Stanley *S.* Derby	1095	38.1	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	LAMP (3M MDS) PCR-*inv*A and -*16S rRNA* genes Multiplex PCR	(Mejia *et al*., 2020)
Ecuador	Poultry feed	2017-08 to 2017-11	*S.* Infantis	18	33	International guidelines ISO 6579	PCR target genes amplification	(Salazar *et al*., 2019)
Ecuador	Chicken carcasses	2017-11 to 2018-11	*S.* Infantis	335	55.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	WGS-MLST	(Mejía *et al*., 2020)

Ecuador	Eggs	NA	*S.* Enteritidis	150	0.01	International guidelines ISO 6579	None	(Sánchez, 2013)
Ecuador	Blood sausage	NA	*Salmonella* spp.	4	25	3M Petrifilm *S.* Express System	None	(Campoverde, 2015)
	Chorizo		*Salmonella* spp.	13	30.6			
Ecuador	Chicken skin	NA	*S.* Infantis	75	80	International guidelines ISO 6579	None	(Villagómez, 2015)
Ecuador	Chicken feed raw materials	NA	*Salmonella* spp.	177	0.6	International guidelines ISO 6579	PFGE	(Sánchez, 2016)
	Chicken skin before chiller		*Salmonella* spp.	20	28.3			
	Chicken skin after chiller			20	15			
Ecuador	Eggshells	NA	*S.* Enteritidis	99	2	Immunochromatography (kit Reveal 2.0 for *Salmonella*)	None	(Solano, 2016)
Ecuador	Raw feed materials (poultry meat meal, hydrolyzed fish meal, rice, wheat bran, palm kernel cake, soy, corn, rice meal)	NA	*S.* Infantis *S.* Mbandaka *S.* Amsterdam	177	0.5	International guidelines ISO 6579	ERIC-PCR and PFGE	(Vinueza-Burgos *et al.*, 2019)
	Chicken carcass (after washing)		*S.* Infantis	25	88			
	Chicken carcass (after chilling)			25	56			
Honduras	Beef carcasses		*S.* Typhimurium	555	10.1			

		2011-02 to 2013-01	*S.* Derby			Pre-enrichment, selective enrichment, culture on selective media, further examination	BAX System PCR Assay	(Maradiaga *et al*., 2015)
	Fresh vegetables and fruits (cantaloupes, cilantro, cucumbers, leafy greens, peppers, tomatoes)		*Salmonella* spp.	573	2.1			
Mexico	Chorizo and sausage	1986-05 to 1987-04	*Salmonella* spp.	89	26.45	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Bello-Pérez *et al*., 1990)
	Beef			54	16.07			
	Pork			47	13.99			
	Charqui			43	12.80			
	Chicken meat			31	9.22			
	Chicken liver			18	5.36			
	Whole fish			16	4.76			
	Beef enchilada			11	3.27			
	Ground pork			7	2.08			
	Ground beef			7	2.08			
	Pork giblets			6	1.80			
	Beef liver			4	1.19			
	Fish fillet			3	0.89			
Mexico	Raw pork		*S.* Derby *S.* Anatum	50	76	Pre-enrichment, selective enrichment, culture on	None	(Kuri *et al*., 1996)

	Chorizo	1994-01 to 1994-03	*S.* Bredeney *S.* Agona *S.* Heidelberg *S.* Muenster *S.* Worthington *S.* Saintpaul *S.* Muenchen *S.* Typhimurium *S.* Brandenburg *S.* Give *S.* Infantis *S.* Senftenberg *S.* Eko *S.* Enteritidis *S.* Havana *S.* Kentucky *S.* Lockleaze *S.* London *S.* Mbandaka *S.* Newbrunswick *S.* Orion *S.* Panama *S.* Roterberg *S.* Tennessee	50	46	selective media, biochemical characterization		
Mexico	Clams	1998-01 to 1998-11	*S.* Anatum *S.* Choleraesuis *S.* Edimburg *S.* Enteritidis *S.* Typhimurium *S.* Agona *S.* Gallinarum	260	11	Bacteriological Analytical Manual (US-FDA)	None	(Quiñones-Ramírez *et al*., 2000)

Mexico	Tomatoes	1999 to 2003	*Salmonella* spp.	681	2.8	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Orozco *et al*., 2008)
Mexico	Taco dressing	2000	*S.* Enteritidis	103	5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Estrada-Garcia *et al*., 2004)
Mexico	Pork	2001 to 2002	*S.* Meleagridis *S.* Havana *S.* Agona *S.* Anatum *S.* Reading *S.* Worthington *S.* Typhimurium *S.* Adelaide *S.* Infantis *S.* Derby	339	58.1	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PFGE	(Zaidi *et al*., 2006)
	Beef		*S.* Meleagridis *S.* Anatum *S.* Reading *S.* Agona *S.* Worthington *S.* Cerro *S.* Havana *S.* Albany *S.* Derby *S.* Infantis	126	54			
	Poultry		*S.* Albany *S.* Enteritidis *S.* Agona *S.* Meleagridis	295	39.7			

			S. Stanleyville *S.* Braenderup *S.* Cannstatt *S.* Reading *S.* Adelaide *S.* Havana					
Mexico	In-field cantaloupe melon	2003-09 to 2004-07	*Salmonella* spp.	35	25.7	Mexican official method (NOM-114-SSA1-1994)	PCR-*oriC* gene	(Espinoza-Medina *et al*., 2006)
	Packed cantaloupe melon			34	20.6			
Mexico	Tomatoes	2003 to 2004	*S.* Montevideo *S.* Newport	906	1.8-10.4	Pre-enrichment, selective enrichment, culture on selective media, further examination	PFGE	(Orozco, Iturriaga *et al*., 2008)
Mexico	Raw vegetables (celery, watercress, beet, broccoli, zucchini, white round onion, cilantro, cabbage, cauliflower, spinach, large lettuce, Romaine lettuce, potato, "papaloquelite" or Mexican	2004-10 to 2005-03	*S.* Typhimurium *S.* Choleraesuis *S.* Gallinarum *S.* Anatum *S.* Agona *S.* Edinburg *S.* Enteritidis *S.* Pullorum	1700 (100 samples of each vegetable)	5.7	Not indicated	None	(Quiroz-Santiago *et al*., 2009)

	cilantro, parsley, Chinese parsley, purslane)							
Mexico	Cantaloupe melon	2005-01 to 2005-04	*Salmonella* spp.	104	12	Pre-enrichment, selective enrichment, culture on selective media, further examination	PCR-invA gene	(Morales-Hernández *et al*., 2009)
Mexico	Cantaloupe melon	2006-04 to 2006-06	*S.* Typhimurium	15	40	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-RFLP	(Gallegos-Robles *et al*., 2008)
	Chile pepper var. Bell		*S.* Typhimurium *S.* Enteritidis	13	31			
Mexico	Poultry meat	2007-01 to 2008-08	*Salmonella* spp.	116	35.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Miranda *et al*., 2009)
	Raw cheese			33	30.3			
	Crude vegetable foods			78	21.8			
	Pork			81	17.3			
	Beef			73	15.1			
Mexico	Beef carcasses	2008-12 to 2009-09	*S.* Give *S.* Typhimurium *S.* Infantis *S.* Anatum *S.* Bovismorbificans *S.* Montevideo *S.* Havana *S.* Muenster *S.* Enteritidis *S.* Livingstone *S.* Oranienburg *S.* Panama	505	15.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	Multiplex PCR for *inv*A and *fim*A genes	(Perez-Montaño *et al*., 2012)

			S. Sinstorf					
Mexico	Bell pepper	2009-05 to 2010-05	*Salmonella* spp.	62	6.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Avila-Vega *et al*., 2014)
Mexico	Beef cattle carcasses at pre-evisceration	2009-07 to 2009-12	*S.* Anatum *S.* Montevideo *S.* Tennessee *S.* Kentucky *S.* Muenster *S.* Give *S.* Reading *S.* Mbandaka *S.* Meleagridis *S.* Fresno	NA	49	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Narváez-Bravo *et al*., 2013)
	Beef cattle carcasses at pre-cooler			NA	24.8			
	Beef cattle carcasses at cooler			NA	6			
Mexico	Ground beef	2009-09 to 2010-07	*S.* Anatum *S.* Agona *S.* Infantis *S.* Havana *S.* Typhimurium *S.* Derby *S.* Sinstorf *S.* Panama *S.* Brandenburg *S.* Give *S.* Rissen *S.* Saintpaul *S.* Albany *S.* Braenderup *S.* Bredeney *S.* Kentucky *S.* Lockleaze	238	56.7	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Cabrera-Diaz *et al*., 2013)

			S. Worthington *S.* Adelaide *S.* Azteca *S.* Cannstatt *S.* Montevideo *S.* Muenchen *S.* Muenster *S.* Reading					
Mexico	Ground beef	2010-01 to 2010-12	*S.* Anatum *S.* Newport *S.* Typhimurium *S.* Derby	864	29.7	Bacteriological Analytical Manual (US-FDA)	None	(Villalpando-Guzmán *et al*., 2017)
	Chicken meat		*S.* Anatum *S.* Newport *S.* Typhimurium *S.* Gallinarum *S.* Derby *S.* Pullorum	864	47.7			
	Pork meat		*S.* Anatum *S.* Newport *S.* Typhimurium *S.* Derby	864	22.5			
Mexico	Beef cattle carcasses	2010	*S.* Typhimurium *S.* Enteritidis	109	8.3	Norma oficial mexicana NOM-114-SSA1-1994	PCR resistant genes	(Varela-Guerrero , *et al*., 2013)
Mexico	Fresh cheeses	2011-02 to 2011-06	*Salmonella* spp.	52	4	Bacteriological Analytical Manual (US-FDA)	None	(Guzman-Hernandez *et al*., 2016)
Mexico	Fresh Maradol papaya	2011-05 to 2011-08	*S.* Agona	388	16	Not indicated	PFGE	(Mba-Jonas *et al*., 2018)

Mexico	Raw whole nopalitos	2014-07 to 2015-06	*Salmonella* spp.	100	30	Bacteriological Analytical Manual (US-FDA)	None	(Gómez-Aldapa *et al*., 2017)
	Raw nopalitos cut into small squares			100	30			
	Cooked nopalitos salad			100	10			
Mexico	Red chorizo	2015-10 to 2016-04	*Salmonella* spp.	15 15 6 9 30	20 60 33.3 11.1 30	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Becerril *et al*., 2019)
Mexico	Chicken meat	2016-01 to 2018-12	*S. enterica*	1160	18	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A and -*16S rRNA* genes	(Regalado-Pineda *et al*., 2020)
Mexico	Wrapped chocolate	NA	*S.* Agona *S.* Derby	44	4.5	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization and reactivity with *Salmonella* spp. antiserum	None	(Torres-Vitela *et al*., 1995)
	Nonwrapped chocolate			56	1.8			
Mexico	Chorizo (raw pork sausage)	NA	*S.* Derby *S.* Anatum *S.* Infantis *S.* Typhimurium *S.* Brandenburg *S.* Worthington *S.* Saintpaul *S.* Schwarzengrund *S.* Aequatoria *S.* Senftenberg	200	88.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Escartin *et al*., 1999)

			S. Minnesota *S.* Give *S.* Binza *S.* Ohio					
Mexico	Ground meat	NA	*Salmonella* spp.	88	11.4	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Heredia *et al*., 2001)
Mexico	Orange juice from street vendors	NA	*S.* Agona *S.* Typhimurium *S.* Anatum	49	14.3	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Castillo *et al*., 2006)
	Orange juice from public markets			51	3.9			
Mexico	Zucchini fruit	NA	*Salmonella* spp.	100	10	Bacteriological Analytical Manual (US-FDA)	None	(Castro-Rosas *et al*., 2010)
Mexico	Jalapeño pepper	NA	*Salmonella* spp.	100	12	Bacteriological Analytical Manual (US-FDA)	None	(Castro-Rosas *et al*., 2011)
	Serrano pepper			100	10			
Mexico	Chicken liver	NA	*S.* Typhimurium	520	1.34	Pre-enrichment, selective enrichment, culture on selective media, further examination	ERIC-PCR	(Talavera *et al*., 2011)
Mexico	Lettuce	NA	*Salmonella* spp.	75	13	Pre-enrichment, selective enrichment, culture on selective media, further examination	PCR-*inv*A gene	(Castañeda-Ramírez *et al*., 2011)
Mexico	Fresh cheese	NA	*Salmonella* spp.	200	27	Bacteriological Analytical Manual (US-FDA)	None	(Torres-Vitela *et al*., 2012)
Mexico	Fresh carrot juice	NA	*Salmonella* spp.	280	8.6	Bacteriological Analytical Manual (US-FDA)	None	(Torres-Vitela,

								Gómez *et al*., 2012)
Mexico	Beef steak	NA	*Salmonella* spp.	90	8.9	Pre-enrichment, selective enrichment, culture on selective media, further examination	PCR-*inv*A gene	(Rubio *et al*., 2013)
Mexico	Ready-to-eat raw vegetable salad	NA	*Salmonella* spp.	220	6.8	Bacteriological Analytical Manual (US-FDA)	None	(Gómez-Aldapa *et al*., 2013)
Mexico	Corn tortillas	NA	*Salmonella* spp.	200	2	Bacteriological Analytical Manual (US-FDA)	None	(Gómez-Aldapa, Rangel-Vargas, Cruz *et al*., 2013)
Mexico	Fresh raw beetroot (*Beta vulgaris*) juice	10-week study period in the summer	*S.* Typhimurium *S.* Enteritidis	100	4	Bacteriological Analytical Manual (US-FDA)	None	(Gómez-Aldapa *et al*., 2014)
Mexico	Eggshell	3-months period	*Salmonella* spp.	2650	16	BCM, bacterial culture method	CM-n-PCR, combined method of enrichment and nested PCR	(Guzmán-Gómez *et al*., 2013)
	Egg yolk				3			
Mexico	Alfalfa sprouts	10-week study period in the summer	*S.* Typhimurium *S.* Enteritidis	100	4	Bacteriological Analytical Manual (US-FDA)	None	(Rangel-Vargas *et al*., 2015)

Mexico	Beef carcasses	NA	*S.* Typhimurium *S.* Sinstorf *S.* Anatum *S.* Infantis *S.* Agona *S.* Montevideo *S.* Rissen *S.* Derby *S.* Give *S.* Azteca *S.* Havana *S.* Cannstatt *S.* Bredeney *S.* Adelaide *S.* Kaapstad *S.* Panama *S.* Lockleaze *S.* Mbandaka *S.* Bonn *S.* Muenchen *S.* Muenster *S.* Brandenburg *S.* Braenderup *S.* Reading *S.* Saintpaul *S.* Sandiego	142	18	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Martínez-Chávez *et al*., 2015)
	Beef chunks			84	39			
	Ground beef			65	71			
Mexico	Raw carrots	NA	*S.* Typhimurium *S.* Montevideo *S.* Gaminara	100	11	Bacteriological Analytical Manual (US-FDA)	None	(Gutiérrez-Alcántara *et al*., 2016)
Mexico	Flavored waters	NA	*Salmonella* spp.	48	16.6	Pre-enrichment, selective enrichment, culture on	None	(Valadez *et al*., 20178)
	Fruit salads			20	15			

						selective media, biochemical characterization		
Mexico	Fresh cheese	NA	*Salmonella* spp.	90	15.38	Not indicated	qPCR	(Chávez-Martínez *et al*., 2019)
Paraguay	Processed and unprocessed chicken meat	2011-10 to 2012-04	*S.* Mbandaka *S.* Albany	60	7	International guidelines ISO 6579	None	(Weiler *et al*., 2017)
Peru	Frozen shrimp	1989 to 1990	*Salmonella* spp.	2	50	Not indicated	None	(Gecan *et al*., 1994)
Peru	Fresh vegetables (lettuce, cabbage, spinach)	2003-10 to 2004-12	*Salmonella* spp.	180	10	Pre-enrichment, selective enrichment, culture on selective media, further examination	None	(Muñoz *et al*., 2013)
Peru	Swine carcasses	Start 2012-03	*S.* Derby	300	6.3	International guidelines ISO 6579	None	(Salvatierra *et al*., 2015)
Peru	Pork (chop)	NA	*Salmonella* spp.	30	6.6	International guidelines ISO 6579	PCR-*inv*A gene	(Ruiz-Roldán *et al*., 2018)
	Beef (loin)			44	2.3			
	Chicken (leg)			64	28.1			
Uruguay	Eggs	2000 to 2002	*S.* Enteritidis *S.* Derby *S.* Panama *S.* Gallinarum	12400	0.005	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	RAPD amplification	(Betancor *et al*., 2010)
Uruguay	Boneless beef trim	2005-01 to 2005-03	*S.* Newport	1186	0.4	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Bosilevac *et al*., 2007)
Venezuela	Beef meat (carcasses)	2006-10 to 2006-12	*S.* Saintpaul *S.* Javiana	80	3.5, 4.4, 11.1 (Plants A, B and C)	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Narváez-Bravo, Rodas-

								González *et al*., 2013)
Venezuela	Frozen raw shrimp	2008-12 to 2009-12	*S.* Saintpaul *S.* Typhimurium *S.* Tumodi *S.* Tennessee *S.* Kentucky *S.* Mackley *S.* Javiana *S.* Rubislaw *S.* Poona *S.* Caracas *S.* Gaminara *S.* Kikoma *S.* Michigan	1022	2.0	Bacteriological Analytical Manual (US-FDA)	None	(Gómez-Gamboa *et al*., 2012)
Venezuela	Raw ground beef (in raw kibbeh)	2014	*Salmonella* spp.	7	43	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	PCR-*inv*A gene	(Rodriguez-Roque *et al*., 2018)
Venezuela	Chicken carcasses	NA	*S.* Anatum *S.* Bloemfontein *S.* Schwarzengrund *S.* Halmstad *S.* Havana *S.* Ohio *S.* Victoria *S.* Aba *S.* Typhimurium *S.* Ball *S.* Glostrup	45	91	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Rengel & Mendoza, 1984)
Venezuela	Chicken giblets	NA	*S.* Heidelberg *S.* Amager	332	23.2	Pre-enrichment, selective enrichment, culture on	None	(Boscán *et al*., 2005)

			S. Javiana *S.* Idikan			selective media, biochemical characterization		
Venezuela	Raw ground beef	NA	*S.* Schwarzengrund *S.* London *S.* Anatum S. Sinstorf	NA	45	Bacteriological Analytical Manual (US-FDA)	None	(Narváez *et al*., 2005)
	Ground beef reprocessed		*S.* Braenderup		9			
	Texturized soybean meal		*S.* Braenderup *S.* London *S.* Tennessee		45			
Venezuela	Fresh crab meat	NA	*Salmonella* spp.	275	38.9	Pre-enrichment, selective enrichment, culture on selective media, biochemical characterization	None	(Morillo *et al*., 2007)

NA: Data not available.

Table S3. Antimicrobial resistance patterns of nontyphoidal *Salmonella* isolated from various food products in Latin America

Country	Analyzed food	Sampling date	Isolated NTS serotype	No. of isolates	Resistance pattern	Method	Number of tested drugs	Interpretation guidelines	Reference
Argentina	Chicken meat	2005-2011	Enteritidis	NA	AMP, FOS, FR, NAL, TET	Kirby–Bauer	14	CLSI, 2009	(Favier *et al*., 2013)
	Chicken giblets		Montevideo	NA	FR, TET				
	Chicken meat		Montevideo	NA	FR				
	Pork sausages		Anatum	NA	TET				
	Liquid egg		Typhimurium	NA	NEO				
Argentina	Pig carcasses	2012 to 2015	Brandenburg	1	AMP, CHL	Kirby–Bauer	16	CLSI, 2014	(Colello *et al*., 2018)
			Typhimurium	6	AMP, CEF, FOX, GEN, TET, NAL, SXT, CHL				
	Pork meat/minced pork meat		Typhimurium	2	AMP, FOX, GEN, TET				
	Retail market pork meat		Typhimurium	1	AMP, CEF, GEN, TET, NAL, CHL, FOS				
	Retail market minced pork		Typhimurium	5	AMP, AMK, TET, NAL				
			Agona	1	FOX, GEN, AMK, CST				
Argentina	Chicken livers	2015-10 to 2016-05	Enteritidis	9	ERY	Kirby–Bauer	30	CLSI, 2013, 2015	(Procura *et al*., 2017)
			Typhimurium	2	ERY				
			Schwazengrund	39 11	ERY STR				
Brazil	Raw and pasteurized milk	1994-09 to 1995-06	Montevideo	2	KAN, RIF, STM, TET	Kirby–Bauer	15	NA	(Padilha *et al*., 2001)
Brazil	Broiler carcasses	1995-05 to 1996-04	Enteritidis	80 3 16 1 3	CST, ERY, NOV, TET ENR FOS KAN NEO	Kirby–Bauer	16	CLSI, 2001	(Cardoso *et al*., 2006)

				76 69	NIT SUL				
Brazil	Broiler chicken parts (wings, whole legs, boneless breasts, and backs)	1996-09 to 1996-12	Enteritidis	2 6 2 1 2 5	TET NAL, TET NIT, TET NAL, NIT ENR, NAL, TET NAL, NIT, TET	Kirby–Bauer	12	CLSI, 2003	(Ribeiro *et al*., 2007)
			Hadar	3	STR, TET				
			Typhimurium	1	NAL, TET				
Brazil	Chicken products and eggs	1997-05 to 1998-04	Enteritidis	NA	PEN	Kirby–Bauer	11	NA	(Baú *et al*., 2001)
	Chicken products and eggs		Anatum	NA	PEN				
Brazil	Pork meat	1999 to 2002	Derby	25 15 16 1 2 1	STR+SPT, SUL, TET SUL, SXT, TET TET CHL, AMP, NAL, TET AMP, NAL, TET SUL, SXT, AMP, NAL, TET	Kirby–Bauer	14	CLSI, 2002	(Michael *et al*., 2006)
Brazil	Cold chicken	1995 to 2013	Typhimurium	1 1 1 1	STR STR, SUL SUL AMP, NAL, SXT, CHL, TET, GEN, STR, SUL	Kirby–Bauer	12	CLSI, 2015	(Almeida *et al*., 2018)

	Chicken			1 2	SUL CTX, FEP, AMP, SUL, CRO				
	Raw pork sausage			1 1	SUL TET, STR, SUL				
	Lettuce			1	STR, SUL				
	Raw kafta			1	TET, STR, SUL				
	Raw tuscan sausage			1	STR				
	Swine			1 1 3 1 1 1 1	AMP, TET, STR, SUL NAL, TET, STR, SUL TET, STR, SUL AMP, NAL, STR, SUL NAL, TET, GEN, STR, SUL TET, GEN, STR, SUL SUL				
	Poultry			1 1	TET, SUL CTX, ATM, FEP, AMP, SXT, TET, STR, SUL, CRO				
	In natura meat			2	SUL				
	Frozen chicken carcass			1 1	STR, SUL TET, SUL				
	Raw salad			1	SUL				
	Homemade swine salami			1	SUL				
	Roast beef			1	SUL				
Brazil	Mesenteric lymph nodes of pigs, tonsils from pigs and minced pork	1999-09 to 2001-10	Agona	1 1 2	CHL, MIN+TET, SUL, TMP CHL, MIN+TET, STR, SPT, SUL, TMP	Kirby–Bauer	17	CLSI, 2002	(Michael *et al*., 2006)

					AMP, CHL, KAN, MIN+TET, STR, SUL, TMP				
Brazil	Poultry carcass	1995 to 2003	Enteritidis	7 6 1	SUL SXT NAL	Kirby–Bauer	11	CLSI, 2005	(Vaz *et al*., 2010)
	Raw poultry meat			2 2 1 2 1	SUL, SXT SXT NAL, SUL NAL, SXT NAL				
	Poultry viscera			1 5 3 1 1 2 1 1	SUL SXT NAL, SUL NAL, SXT NAL, SUL, SXT NAL STR, GEN, SUL STR, SUL				
	Food related to poultry meat or eggs			2	SUL				
Brazil	Meals with eggs or other poultry product	1995 to 1997	Enteritidis	1 2 10 8 1 1 1	NAL NIT SUL TET TMP SUL, NIT SUL, TET, NIT	Kirby–Bauer	12	CLSI, 2001	(Oliveira *et al*., 2005)
	Broiler carcasses			4 14 2	SUL SUL, NIT SUL, STR, TET, NIT				

	Poultry derived products (viscera)			2 1 8 3 1 1 1 1 1 1 1	SUL SUL, NAL SUL, NIT SUL, NIT, NAL SUL, STR, GEN SUL, NIT, NAL, CEF SUL, STR, GEN, NIT SUL, STR, TET, GEN, NIT SUL, STR, NOR, GEN, NIT SUL, STR, NOR, GEN, NIT, NAL CHL, SUL, TMP, STR, GEN, CEF, AMP				
Brazil	Frozen chicken	1998 to 2000	Enteritidis	1 6	SUL TET	NA	12	CLSI, 1997	(Wilson, 2004)
			Hadar	2	SUL				
			Infantis	1	TET				
Brazil	Mesenteric lymph node of swine and inguinal lymph node of swine	2000 to 2012	Typhimurium	1 3 1 1 1 2 1 1 2 4	AMP, NAL, LVX, SXT, CHL, CIP, TET AMP, NAL, SXT, CHL, TET AMP, NAL, SXT, CHL AMP, SXT, CHL, TET AMP, SXT, CHL AMP, CHL, TET NAL, SXT, TET AMP, CHL AMP, TET TET	Kirby–Bauer	13	CLSI, 2014	(Almeida *et al*., 2016)

Brazil	Pig liver	2000 to 2016	Typhimurium	1	CHL, TET, CIP, GEN, NAL, SXT, AMP, STR	NA	NA	NA	(Monte *et al*., 2019)
	Pork		Typhimurium	1	CHL, TET, CIP, GEN, NAL, SXT, AMP, STR				
	Swine stomach		Typhimurium	1	CHL, TET, CIP, NAL, AMP, STR				
	Swine muscle		Infantis	1 1	CHL, TET, CIP, AMP, STR CHL, TET, CIP, NAL, AMP, STR				
	Chicken thigh		Schwarzengrund	1	TET, CRO, CIP, GEN, NAL, TIO, SXT, AMP, STR				
	Chicken wing paddle		Schwarzengrund	1	CIP, NAL				
	Chicken carcass		Schwarzengrund	2 1 10	CIP, NAL TET, CIP, GEN, NAL, SXT, STR TET, CRO, CIP, GEN, NAL, TIO, SXT, AMP, STR				
			Minnesota	2	FOX, TET, CRO, AMC, CIP, NAL, TIO, AMP, STR				
			Newport	2	CRO, CIP, GEN, NAL, TIO, AMP, STR				
	Chicken feet		Minnesota	1	FOX, TET, CRO, AMC, CIP, NAL, TIO, AMP, STR				
	Chicken breast		Brandenburg	1	FOX, TET, CRO, AMC, CIP, NAL, TIO, AMP				

	Chicken wing		Heidelberg	1	FOX, TET, CRO, AMC, CIP, NAL, TIO, AMP, STR				
Brazil	Raw salami after stuffing and salami after curing	2002 to 2003	Panama	3 1 2	AMP, CHL, STX, TET AMP, CHL, STX, TET, ENR AMP, STX, TET	Kirby–Bauer	11	CLSI, 2002	(Ribeiro *et al*., 2007)
	Salami after curing		Brandenburg	1	AMK				
Brazil	Food samples of poultry origin	2002 to 2006	Enteritidis	7	NAL	Kirby–Bauer	6	CLSI, 2006	(Kottwitz *et al*., 2011)
Brazil	Poultry carcass	2002 to 2012	Senftenberg	1	AMK, SPT, STR, AMP, SUL, CHL, FLF, TET	Kirby–Bauer	17	CLSI, 2008, 2013	(Mattiello *et al*., 2015)
Brazil	Poultry	2003 to 2004	Typhimurium	1	ATM, STR, SUL, SXT, TET	Kirby–Bauer	23	CLSI, 2006	(Fernandes *et al*., 2009)
Brazil	Poultry	2003 to 2004	Enteritidis	17	ENR, NAL, SXT, TET	Kirby–Bauer	14	CLSI, 2005	(Ribeiro *et al*., 2011)
			Ouakam	19	CHL, GEN, KAN, NAL, STR, TET				
			Alachua	18	ENR, NAL, SXT, TET				
	Salami		Brandenburg	1	ENR, KAN, NAL, STR				
			Panama	6 3	AMP, CHL, KAN, NAL, STR, SXT, TET AMP, CHL, KAN, STR, SXT, TET				
	Pork ground meat		Panama	5 6	AMP, CHL, KAN, STR, SXT, TET AMP, SXT, STR, TET				
Brazil	Crabs	2003-02 to 2003-05	Senftenberg	NA	NAL, TET	Kirby–Bauer	17	CLSI, 2003	(Vieira *et al*., 2004)
			Poona	NA	NAL, TET				
Brazil	Eggshell's rinse and "Pool" yolk (of discarded hatching eggs)	2003-08 to 2006-12	Enteritidis	6	NAL	Kirby–Bauer	6	CLSI, 2006	(Kottwitz *et al*., 2013)

Brazil	Frozen chicken carcasses	2004-09 to 2006-07	Enteritidis	NA	AMP, ATM, CEF, FOX, CRO, TIO, FLF, CHL, STR, GEN, NAL, CIP, ENR, TET, SUL, TMP, SXT, NIT	MIC	18	CLSI, 2004	(Medeiros *et al*., 2011)
			Infantis	NA	AMP, ATM, TIO, FLF, STR, GEN, NAL, SUL, TMP, SXT				
			Typhimurium	NA	AMP, ATM, TIO, FLF, STR, GEN, NAL, ENR, TET, SUL, TMP, SXT				
			Heidelberg	NA	AMP, ATM, CEF, FOX, CRO, TIO, FLF, STR, NAL, SUL				
Brazil	Fresh pork sausages	2005-03 to 2005-08	Typhimurium	NA	AMP, NEO, SUL, TET	Kirby–Bauer	14	NA	Spricigo *et al*., 2008
Brazil	Fresh pork sausages	2005-09 to 2006-04	Derby	NA	SUL, TET, TOB	Kirby–Bauer	15	CLSI, 2001	Spricigo, Matsumoto, Espíndola and Ferraz, 2008
			Schwarzengrund	NA	SUL				
			Typhimurium	NA	TET, TOB				
Brazil	Pig meat cuts	2006-06 to 2006-08	Typhimurium	NA	TMP, ATM, CIP, CRO, FOX, TET, KAN	Kirby–Bauer	14	CLSI, 1984	(Tessmann *et al*., 2008)
			Infantis	NA	TMP, ATM, CIP, CRO, FOX, SUL				
			Panama	NA	AMP, CAR, CHL, TET, KAN				

Brazil	Swine mesenteric lymph nodes, Swine head lymph nodes, Swine tonsils	2007	Bredeney	34 1 2 2 3 2 4	SUL, TMP, TET+MIN, CHL, STR, KAN, AMP SUL, TMP, TET+MIN, CHL, STR, KAN, AMP, FLF TMP, TET+MIN, CHL, KAN TET+MIN, CHL SUL, TET+MIN, CHL, STR, KAN, AMP SUL, TMP, TET+MIN, STR, SPT, AMP TET+MIN, STR	Kirby–Bauer	16	CLSI, 2002, 2003	(Michael *et al*., 2008)
Brazil	Chicken carcass	2008 to 2009	Schwarzengrund	1	AMP, CAZ, CRO, CTX, TIO, FEP, NAL, CIP, ENR, TET, STR, SXT	MIC	12	CLSI, 2008, 2011	(Silva *et al*., 2013)
	Turkey carcass		Agona	1	AMP, CAZ, CRO, CTX, TIO, FEP, NAL, CIP, ENR, TET, STR, SXT				
	Chicken eggs		Agona	1	AMP, CAZ, CRO, CTX, TIO, FEP, NAL, CIP, ENR, TET, STR, SXT				
Brazil	Pig carcasses	2008 to 2011	Typhimurium	1 4 1 1 5 11 1 6 1	NAL, STR, TET AMP, GEN, KAN, TET AMP, NAL, TET, TMP CHL, STR, SUL, TET AMP, GEN, KAN, NAL, TET AMP, NAL, STR, SUL, TET, TMP AMP, CHL, GEN, STR, SUL, TET	Kirby–Bauer	12	CLSI, 2013	(Lopes *et al*., 2015)

				1	AMP, CHL, KAN, STR, SUL, TET AMP, CHL, GEN, NAL, STR, SUL, TET, TMP AMP, CHL, CIP, GEN, NAL, STR, SUL, TET, TMP				
			Enteritidis	1	STR, SUL, TET				
			Derby	18	STR, SUL, TET				
			Infantis	1	AMP, CHL, TET, TMP				
			Panama	4 2	AMP, CHL, KAN, STR, SUL, TET AMP, CHL, KAN, NAL, STR, SUL, TET				
			Ohio	1	AMP, CHL, NAL, STR, SUL, TET				
Brazil	Chicken meat	2009 to 2010	Infantis	14 4 2 3 1 3	AMX SUL TET AMX, CAZ AMX, SUL TET, SUL	Kirby–Bauer	10	CLSI, 2013	(Mendonça *et al*., 2020)
Brazil	Chicken meat	2009 to 2012	Albany	1 1	CIP, ENR, NAL, TET, SXT FOX, CIP, ENR, NAL, TET, SXT	Kirby–Bauer	15	CLSI	(Penha *et al*., 2019)
			Worthinghton	1	CIP, NAL, TET, CHL				

			Senftenberg	1	FOX, CIP, ENR, NAL, SXT				
			Kentucky	1 1	FOX, CIP, NAL, TET, SXT FOX, CIP, ENR, NAL, TET, SXT				
Brazil	Chicken meat	2010	Minnesota	1	AMC, CRO, TIO, TET, SXT	Kirby–Bauer	9	CLSI, 2013	(Moura *et al*., 2017)
Brazil	Chicken meat	2010 to 2015	Heidelberg	95 1 1 1 1 1 15 13	AMP, CTX, CAZ, CIP, NAL, SXL, TET AMP, CTX, CAZ, CIP, NAL, SXL, TET, GEN AMP, CTX, CAZ, CIP, NAL, SXL, TET, CST AMP, CTX, CAZ, CIP, NAL, SXL, TET, CHL, TMP AMP, CTZ, CAZ, SXL, TET SMP, CTX, CIP, NAL, SXL, TET, GEN CIP, NAL, SXL, TET, GEN CIP, NAL, SXL, TET	MIC	10	EUCAST, 2017	(van den Berg *et al*., 2019)
Brazil	Poultry (heart)	2010-08 to 2011-06	Agona	2 1	SXL, SUL, AMC TIO	Kirby–Bauer	12	CLSI, 2011	(Minharro *et al*., 2015)
	Poultry (carcass)		Anatum	1	SXL, SUL, AMC				
	Poultry (heart, liver, and carcass)		Enteritidis	10 1	SXL, AMC SUL				
	Poultry (heart and liver)		Infantis	2	SXL, SUL, AMC				

	Poultry (heart, liver, and carcass)		Mbandaka	5 3 1	SXL, AMC ENR SUL				
	Poultry (liver)		Minnesota	1	SXL, SUL, AMC				
	Poultry (heart, liver, and carcass)		Orion	1	SXL, GEN, AMC				
	Poultry (liver)		Panama	1	SXL, SUL, AMC				
	Poultry (heart)		Schwarzengrund	1	SXL, AMC				
Brazil	Cattle carcasses	2010-09 to 2012-02	Livingstone	1	AMP, CLI, CEF, FOX, ERY, NAL, VAN	NA	6	CLSI, 2012	(Loiko *et al*., 2016)
Brazil	Poultry fragments (breast, right and left legs quarter) from carcasses (collected post-bleeding, post-plucking, and post-chilling)	2011-2012	Corvallis	2 4 4	AMP, CRO, CTX NAL, AMP, CRO, CTX, CIP AMP, ATM, CRO, CTX, FEP	Kirby–Bauer	17	CLSI, 2013	(Yamatogi *et al*., 2015)
Brazil	Mayonnaise salad and galinhada	2012-11	Alachua	NA	NAL, CIP	Kirby–Bauer	17	CLSI, 2013	(de Almeida *et al*., 2015)
Brazil	Poultry meat	2013-2016	Heidelberg	1	CST	Kirby–Bauer, MIC	9	CLSI, 2008	(Moreno *et al*., 2019)
			Derby	1	CST				
			Abony	2	CST				
			Muenchen	1	CST, FLF				
			Schwarzengrund	1 1	CST, FLF CST				
Brazil	Chicken sausage	2014 to 2016	Heidelberg	1	AMP, AMC, CAZ, CTX, CRO, CFX	Kirby–Bauer, MIC	8	CLSI, 2015	(Tiba-Casas *et al*., 2019)
Brazil		2014 to 2017	Saintpaul	1	CST, CHL	MIC	13		

	Retail poultry, turkey, pork meat and pork carcasses		Typhimurium	1 2 1 1 1 1	CST, AMP, CIP, GEN, NAL, TET CST, AMP, CHL, CIP, GEN, NAL, SXT, TET, TGC CST, AMP, CIP, NAL CST, AMP, CHL, CIP, GEN, NAL, TET, TGC CST, AMP, AZM, GEN, SXT, TET, TGC CST, AMP, CHL, TET, TGC			EUCAST, 2019	(Rau *et al.*, 2020)
Brazil	Chicken carcasses	2014-01 to 2015-05	Abony	NA	SUL	Kirby–Bauer	17	CLSI, 2014	(da Cunha-Neto *et al.*, 2018)
			Agona	NA	SUL				
			Anatum	NA	SUL				
			Infantis	NA	SUL				
			Schwarzengrund	NA	SUL				
Brazil	Chicken cuts (wing, breast, leg) and fried chicken	2015-08 to 2016-02	Typhimurium	4 2	AMP, GEN, DOX, TET, NAL, CRO, FEP, ATM AMP, DOX, TET, NAL, CRO, FEP, ATM	Kirby–Bauer	15	CLSI, 2008, 2013	(Perin *et al.*, 2019)
			Heidelberg	1 3	AMP, AMC, DOX, TET, NAL, TOB, CRO, FEP, ATM AMP, GEN, DOX, TET, NAL, CRO, FEP, ATM				
			Ndolo	1 2	AMP, GEN, DOX, TET, CRO, FEP, ATM AMP, GEN, DOX, TET, NAL, CRO, FEP, ATM				

Chile	Meat	1975 to 1993	Panama	7 61 2 2	STR, SPT STR, SPT, SUL, TET KAN, STR, SPT, SUL, TET AMP, GEN, KAN, STR, SPT, SUL, TET	Kirby–Bauer, MIC	16	NA	(Cordano & Virgilio, 1996)
	Vegetables			3 7	STR, SPT STR, SPT, SUL, TET				
	Shellfish			9 2	STR, SPT STR, SPT, SUL, TET				
	Goat cheese			12	STR, SPT				
	Fish meal			6	STR, SPT, SUL, TET				
Chile	Food intended for human consumption	2007-06 to 2009-06	Derby	1 1	AMX, AMP, TIO, ENR, FLF, OXY, SXT TIO, OXY, SXT	Kirby–Bauer	7	CLSI, 2008	(Junod *et al*., 2013)
Colombia	Poultry, meat, and mixed sources	1997 to 2002	Typhimurium	2 2 2 1 1 2 1 1	SXT, AMP SXT, AMP, TET SXT, AMP, TET, NAL SXT, AMP, TET, CHL SXT, TET, NAL TET TET, GEN TET, CTX, AMP	Kirby–Bauer	8	CLSI, 2002	(Wiesner *et al*., 2006)
Colombia	Bovine meat	2002 to 2009	Carrau	1	NAL	Kirby–Bauer, MIC	15	CLSI, 2007	(Karczmarczyk *et al*., 2010)
	Cheese			2	NAL				
	Ground meat			1	NAL, TET				
	Cheese		Anatum	1 1	AMC, AMP, CEF, TET STR, TET				
	Ground meat			1	NAL				
	Sausages			1 1	TET GEN, STR, TET				

	Ham			1	NAL				
	Cheese		Infantis	1	STR				
	Retail chicken			1	KAN, NEO, NAL, STR, TET				
	Sausages			1	AMP				
	Potato and meat			1	AMP				
	Retail chicken		Uganda	1	STR				
	Sausages			1 1	KAN, NEO, NAL, STR, TET TET				
	Ground meat			1 1 1 1	KAN, NEO, NAL, STR, TET KAN, NEO, TET NAL, TET AMP				
	Retail chicken		Braenderup	1	TET				
	Ham			1	AMP				
	Ground meat			1	AMP				
	Sausages			1 1	TET AMP				
	Bovine meat			1	CEF				
	Bovine meat		Saintpaul	1	AMP				
	Potato		Muenchen	1	NAL				
	Cheese			1 1 1	TET AMP NAL, TET				
	Ham		Derby	1	TET				
	Meat (bovine)		Bredeney	1	AMP				
	Ground meat		Senftenberg	1	AMP				
	Sausages		Javiana	1	AMP				
	Sausages		Fresno	1	AMP				

	Ground meat		Gaminara	1	AMP				
Colombia	Poultry meat	2009-03 to 2009-10	Heidelberg	2 3 1 1 1	AMC, AMP, CFZ, FOX, CRO, CTX, TIO, NAL, CIP, ENR, TET, TIL AMC, AMP, CFZ, FOX, CRO, CTX, TIO, NAL, TET, TIL NAL, CIP, ENR, STR, TET, TIL NAL, CIP, ENR, TET, TIL NAL, CIP, TET, TIL	MIC	21	CLSI, 2012	(Donado-Godoy *et al.*, 2015)
			Enteritidis	1 1 1 6	TIL, NIT TIL, CFZ TIL, GEN TIL				
			Typhimurium	1 1 1	STR, TET, SXT, TIL STR, TET, TIL STR, TIL				
Colombia	Atoll rice	2010	Typhimurium	11	TET, STR	Kirby–Bauer, MIC	13	CLSI, 2010	(Díaz *et al.*, 2014)
Colombia	Chicken sandwich (bread, cooked shredded chicken, green tomato, pineapple, and homemade garlic sauce)	2011-03	Enteritidis	1	NAL	Kirby–Bauer, MIC	12	CLSI, 2012	(Díaz *et al.*, 2013)

Colombia	Raw chicken meat	2011-08 to 2012-05	Heidelberg	2 1 40 23 52 7 47 19 42 21 46 46 54 59 23 40 67 68 35	GEN TOB STR AMC AMP TZP CFZ FEP CTX FOX TIO CRO CIP ENR LVX NIT NAL TET SXT	Kirby–Bauer, MIC	22	CLSI, 2013	(Donado-Godoy *et al*., 2014)

			Enteritidis	8 5 9 1 7 1 7 8 14 7 7 9 5 49 10 4 4	STR AMC AMP TZP CFZ FEP CTX FOX TIO CRO CIP ENR LVX NIT NAL TET SXT				
			Typhimurium	16 1 8 2 6 4 4 6 4 8 9 4 9 12	STR AMC AMP TZP CFZ FEP CTX TIO CRO CIP ENR LVX NIT NAL				

				12 8	TET SXT				
Colombia	Hen feed and eggshells	2013-01 to 2013-06	Shannon	8 2	AMK, CEF, FOX, CXM, GEN SXT	Kirby–Bauer	13	CLSI, 2006	(Rodríguez *et al*., 2015)
			Enteritidis	6 5	AMK, CEF, FOX, CXM, GEN NIT				
Colombia	Chicken meat	2014-02 to 2014-05	Newport	2	AMK, CFZ, FOX, GEN, TOB	Kirby–Bauer	19	CLSI, 2015	(Cortes *et al*., 2017)
			Skansen	1	AMK, CFZ, FOX, CIP, GEN, NIT, TET, TOB, SXT, ENR				
			Kalina	2	AMK, CFZ, FOX, GEN, TOB				
			Schwarzengrund	1	AMK, CFZ, FOX, CIP, GEN, NIT, TET, TOB, SXT, ENR				

			Manhattan	1	AMK, CFZ, FOX, GEN, TOB				
			Braenderup	2	AMK, CFZ, FOX, GEN, TOB				
			Bovismorbificans	1	AMK, CFZ, FOX, GEN, TOB				
			Typhimurium	1 1	AMK, CFZ, FOX, GEN, TET, TOB, CHL, FLF AMK, CFZ, FOX, GEN, TET, TOB				
			Othmarschen	1	AMK, CFZ, FOX, GEN, TOB				
			Hvittingfoss	1 8	AMK, CFZ, FOX, GEN, TOB, FLF AMK, CFZ, FOX, GEN, TOB				
			Heidelberg	2	AMK, AMP, CFZ, FOX, CIP, GEN, NIT, TET, TOB, SXT, ENR				
			Muenster	5	AMK, AMP, CFZ, FOX, GEN, TET, TOB				
			Budapest	1	AMK, AMP, SAM, CFZ, FOX, CRO, CIP, GEN, NIT, TET, TOB, ENR				
Costa Rica	Poultry compound feed	2009 to 2014	Anatum	NA	TET	Kirby–Bauer, MIC	1	CLSI, 2015	(Molina *et al*., 2015)
	Poultry compound feed		Havana	NA	TET				
	Meat and bone meal		Give	NA	TET				

Cuba	Fresh meat	2008-01 to 2009-12	Agona	3 2 1	TET NAL CRO	Kirby–Bauer	9	CLSI, 2008	(Puig *et al*., 2011)
	Fresh meat		Bissau	1	NAL				
	Fresh meat		Derby	2 1	TET AMP				
	Meat products			1	AMP, TET, NAL				
	Fresh meat		Enteritidis	18 1	TET NAL, CIP				
	Egg-based food			4 1	AMP AMP, TET, NAL				
	Meat products			2	NAL				
	Fresh meat		Hato	1	TET				
	Fresh meat		Infantis	3 1	TET AMP, TET, CRO				
	Dairy products			3	AMP				
	Egg-based foods		Kisii	1	TET				
	Fresh meat			1	NAL, TET				
	Fresh meat		London	2 1 1 1	AMP NAL AMP, TET NAL, CRO				
	Fresh meat		Muenchen	2	TET				
	Fresh meat		Nchanga	2	TET				
	Fresh meat		Shangani	1	TET				
	Fresh meat		Typhimurium	4 1 1	TET CRO AMP, TET				
	Egg-based foods			2	AMP				
	Processed meat		Kande	1	TET				
	Processed meat		Montevideo	1	TET				

	Meat products		Asylanta	2	TET				
	Meat products		Sinstorf	2	TET				
	Egg-based foods		Irumu	1	TET				
Ecuador	Poultry, pork, beef, veal, lamb, turkey	2015 to 2016	Infantis	86 12 27 11 2 3 12 9 10 8	STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, AMP, KAN STR, CTX, CRO, CIP, NAL, TET, AMP STR, CTX, CRO, CIP, NAL, TET, CHL, AMP, KAN STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP STR, CTX, CRO, CIP, NAL, TET, AMP, KAN STR, SXT, CTX, AMC, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, AMC, CRO, CIP, NAL, TET, CHL, GEN, AMP, AZM, KAN STR, SXT, CTX, CRO, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP, AZM, KAN	Kirby–Bauer	13	CLSI, 2020	(Mejía *et al*., 2020)

	Poultry, pork, beef, veal		Dublin	1 1 1 1	AMP, CTX, CRO, CIP, GEN, KAN, NAL, STR, SXT, TET STR, SXT, CTX, AMC, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, AMC, CRO, CIP, NAL, TET, CHL, GEN, AMP, AZM, KAN STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP, AZM, KAN				
	Pork, veal		Typhimurium	1 1 1 1	STR, NAL, TET, CHL STR CIP STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN				
	Beef		Javiana	1	TET				
	Lamb		Heidelberg	2 1 1	STR, SXT, CTX, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, AMC, CRO, CIP, NAL, TET, CHL, GEN, AMP, KAN STR, SXT, CTX, CRO, NAL, TET, CHL, GEN, AMP, KAN				
Ecuador	Poultry feed	2017-08 to 2017-11	Infantis	1 1	TET, NIT, FR, FOS, ENR, CIP, CRO, FEP, AMP, STR	Kirby–Bauer	20	CLSI, 2019	(Sánchez-Salazar *et al*., 2019)

				1 1 1 1 1 1	TET, SXT, NIT, FR, FOS, CHL, CIP, CRO, FEP, AMP, GEN, STR TET, SXT, NIT, FR, FOS, CHL, ENR, CIP, CRO, FEP, AMP, GEN, STR TET, SXT, NIT, FR, FOS, CHL, ENR, CIP, CRO, CAZ, FEP, AMP, GEN, STR TET, NIT, FR, FOSF, CHL, ENR, CIP, CRO, FEP, AMP, GEN, STR TET, NIT, FR, CHL, CIP, GEN, STR TET, CIP TET, SXT, NIT, FR, FOSF, CHL, CIP, CRO, FEP, AMP, GEN, STR TET, SXT, NIT, FR, FOSF, CHL, ENR, CIP, CRO, FEP, AMP, GEN, STR TET, SXT, NIT, FR, FOS, CHL, ENR, CIP, CRO, CAZ, FEP, AMP, GEN, STR TET, NIT, FR, FOS, CHL, ENR, CIP, CRO, FEP, AMP, GEN, STR TET, NIT, FR, CHL, CIP,				

					GEN, STR TET, CIP				
Mexico	Retail chicken, retail pork, retail beef, chicken intestine, swine intestine, bovine intestine	2000 to 2005	Typhimurium	NA	PIP, TIC, FOX, CAZ, CTX, TIO, ATM, SXT, NAL, GEN, KAN	Kirby–Bauer, MIC	11	CLSI, 2000	(Zaidi *et al*., 2006)
Mexico	Chicken meat	2002-03 to 2005-08	Typhimurium	22 20 4 19 17 6 12	AMP, STR SF, TET GEN, KAN CHL CRO NAL SXT	Kirby–Bauer, MIC	11	CLSI, 2000	(Zaidi *et al*., 2008)
	Pork meat			78 113 2 51 60 52 92 123 118 81 120	AMP CHL CIP CRO GEN KAN NAL STR SF SXT TET				

	Beef			25 38 4 24 19 42 50 48 30 49	AMP CHL CRO GEN KAN NAL STR SF SXT TET				
Mexico	Pork meat and intestine; bovine intestine	2006-03 to 2007-05	Typhimurium	1	AMP, FOX, CAZ, CRO, CHL, NAL, STR, SXT, SF, TET	Kirby–Bauer, MIC	12	CLSI, 2009, 2010	(Zaidi *et al*., 2012)
	Beef, chicken meat and intestine, pork meat; fresh fruit beverage		Agona	1 1 1	CHL, STR, SXT, TET, SF SF STR				
Mexico	Beef carcass	2008-12 to 2009-09	Typhimurium	7 5 1	GEN, TET, SXT, CHL, STR, KAN GEN, TET, SXT, CHL, NAL, STR, CIP GEN, TET, SXT, CHL, KAN, STR	Kirby–Bauer	11	CLSI, 2008	(Perez-Montaño *et al*., 2012)
			Infantis	1	GEN, TET, SXT, CHL, STR, KAN				
			Havana	1	AMP, TET, SXT, STR, CIP				
Mexico	Ground beef	2009-09 to 2010-07	Anatum	2 1 1	AMP, TET, SXT, CEF, STR, GEN, CHL AMP, TET, NAL, SXT, STR TET, SXT, STR, CHL	Kirby–Bauer	11	CLSI, 2008	(Cabrera-Diaz *et al*., 2013)

				1 1	TET, NAL, STR, CHL TET, NAL, STR				
			Agona	1	AMP, TET, SXT, STR				
			Havana	1	TET, SXT, STR				
			Typhimurium	1 3 1	AMP, TET, CEF, STR, GEN, CHL TET, NAL, SXT, STR, CHL AMP, TET, STR				
			Derby	1 1 1	AMP, TET, NAL, SXT, STR TET, SXT, STR, CHL TET, NAL, STR				
			Sinstorf	1	AMP, TET, SXT, STR, CHL				
			Panama	1	AMP, TET, SXT, STR, GEN, CHL				
			Brandenburg	1	AMP, TET, SXT, STR				
			Give	1	AMP, TET, NAL, STR, CHL				
			Rissen	1	TET, NAL, SXT, STR, CHL				
			Saintpaul	1 1	AMP, TET, SXT, STR TET, NAL, STR				
			Reading	1	TET, NAL, STR				
Mexico	Chicken meat	2010-01 to 2010-12	Anatum	27 7 2 1	CAR, AMP, CHL, CTX, PEF GEN SXT	Kirby–Bauer	12	CLSI, 2010	(Villalpando-Guzmán *et al*., 2017)

					AMK, CEF, CRO, NET, NIT				
			Newport	16 4 2 1	CAR, AMP, CHL, CTX, PEF GEN CRO, CEF, SXT, NET AMK, NIT				
			Typhimurium	15 2 1	CAR, AMP, CHL, CTX, PEF AMK, CRO, GEN CEF, SXT, NET, NIT				
			Gallinarum	43 30 19 13 10 2 1	AMP CHL CTX CAR, GEN PEF NIT AMK, CRO, CEF, SXT, NET				
			Derby	4 2 1	CAR, AMP, CHL, CTX, PEF CRO, GEN AMK, CEF, SXT, NET, NIT				

			Pullorum	27 22 21 15 9 7 2 1	AMP CHL CTX PEF GEN CAR CRO, CEF, NIT AMK, SXT, NET				
	Beef meat		Anatum	48 39 37 27 23 3 2 1	PEF AMP CHL CAR CTX AMK, NIT CRO, GEN, SXT, NET CEF				
			Newport	22 10 4 3 2 1	CAR, AMP, CHL, CTX, PEF CRO CEF GEN AMK, NET, NIT SXT				
			Typhimurium	34 32 5 4 3 2 1	CAR, AMP, CHL, CTX PEF CRO NIT AMK CEF, SXT, NET GEN				

			Derby	14 13 3 2 1	CAR, AMP, CHL, CTX PEF CRO, GEN SXT, NIT AMK, CEF, NET				
	Pork meat		Anatum	32 4 3 2 1	CAR, AMP, CHL, CTX, PEF CRO AMK CEF, GEN SXT, NIT				
			Newport	37 3 2 1	CAR, AMP, CHL, CTX, PEF NIT CRO, GEN, SXT, NET AMK, CEF				
			Typhimurium	22 3 2 1	CAR, AMP, CHL, CTX, PEF CRO, SXT, NIT AMK, CEF, NET GEN				
			Derby	10 3 2 1	CAR, AMP, CHL, CTX, PEF NIT CEF, GEN, SXT AMK, CRO, NET				
Mexico	Ground beef	2013-04 to 2013-11	Cannsttat	1	AMP, CAR, TET	Kirby–Bauer	14	CLSI, 2012	(Nayarit-Ballesteros *et al*., 2016)
			Lomita	3 1 1 1	AMP, CAR, SXT, TET AMP, CAR, CEF, SXT, TET AMP, CAR, SXT, PEF, TET				

					AMP, CEF, SXT, GEN, TET				
			Senftenberg	1 1	AMP, CAR, SXT, CHL, TET AMP, CAR, CEF, SXT, CHL, GEN, TET				
			Derby	1 1 1	AMP, CAR, SXT, TET AMP AMP, CAR				
			Javiana	1	AMP, CAR, CEF, CHL, TET				
Uruguay	Eggs	2000 to 2002	Enteritidis	2 4	NAL AMP, CEF, FOX, AMC, SAM, CXM	Kirby–Bauer	13	CLSI, 2001	(Betancor *et al*., 2004)
Uruguay	Eggs	2000 to 2002	Panama	2	AMP, CEF, CXM, CAZ	Kirby–Bauer	13	CLSI, 2006	(Betancor *et al*., 2010)
			Gallinarum	1 4	AMP NAL				
			Amager	2 4	AMP NAL				
			Idikan	2 2	NAL TET				
			Javiana	4	NAL				
Venezuela	Raw chicken meat	2016	Heidelberg	1 1 1 1 1	AMP, FOX, TET, SXT AMP, FOX, CAZ, ATM, TET, SXT, GEN, CIP AMP, FOX, CAZ, ATM, TET, SXT, GEN, TOB, CIP AMP, FOX, SXT	MIC	14	CLSI, 2018	(Gonzalez and Araque, 2019)

					AMP, FOX, AZM, TET, SXT				
			Enteritidis	1 1	AMP, TET, SXT AMP, SXT				
			Typhimurium	1	AMP, TET				
			Meleagridis	1	TET, SXT, CIP				

NA: Data not available. **MIC:** Minimum inhibitory concentration. **Antimicrobials:** amikacin (AMK), amoxicillin (AMX), amoxicillin-clavulanic acid (AMC), ampicillin (AMP), ampicillin-sulbactam (SAM), azithromycin (AZM), aztreonam (ATM), carbenicillin (CAR), cefaclor (CEC), cefadroxil (CFR), cefazolin (CFZ), cefepime (FEP), cefotaxime (CTX), cefoxitin (FOX), ceftazidime (CAZ), ceftiofur (TIO), ceftriaxone (CRO), cefuroxime (CXM), cephalothin (CEF), chloramphenicol (CHL), ciprofloxacin (CIP), clindamycin (CLI), colistin (CST), doxycycline (DOX), enrofloxacin (ENR), erythromycin (ERY), florfenicol (FLF), fosfomycin (FOS), furazolidone (FR), gentamicin (GEN), kanamycin (KAN), levofloxacin (LVX), lincomycin (LIN), minocycline (MIN), nalidixic acid (NAL), neomycin (NEO), netilmicin (NET), nitrofurantoin (NIT), norfloxacin (NOR), novobiocin (NOV), oxytetracycline (OXY), pefloxacin (PEF), penicillin (PEN), piperacillin (PIP), piperacillin-tazobactam (TZP), rifampicin (RIF), spectinomycin (SPT), streptomycin (STR), sulfafurazole (SOX), sulfamethoxazole (SXL), sulfamethoxazole-trimethoprim (SXT), sulfisoxazole (SF), sulphazotrim (STM), sulfonamide (SUL), tetracycline (TET), ticarcillin (TIC), tigecycline (TGC), tilmicosin (TIL), trimethoprim (TMP), Tobramycin (TOB), vancomycin (VAN).

References

Abrantes M, Sousa AC, Araújo N de, Sousa Ê de, Oliveira A de, Silva J da. Avaliação microbiológica de carne de charque produzida industrialmente. Arq Inst Biol 2014;81(3):282–285.

Albuquerque R, Ito N, Miyaji C. Estudo da ocorrência de salmonelas em ingredientes, rações e suabes de pó colhidos em uma fábrica industrial de ração. Braz J Vet Res Anim Sci 1999;36(6):324–326.

Alexandre M, Pozo C, González V, Martínez MC, Prat S, Fernández A, Fica A, Fernández J, Heitmann I. Detection of *Salmonella* enteritidis in samples of poultry products for human consumption in the Chilean Metropolitan Area. Rev Méd Chile 2000;128(10):1075–1083.

Almeida F, Medeiros MI, Kich JD, Falcão JP. (2016). Virulence-associated genes, antimicrobial resistance and molecular typing of *Salmonella* Typhimurium strains isolated from swine from 2000 to 2012 in Brazil. J Appl Microbiol 2016;120(6):1677–1690.

Almeida F, Seribelli AA, Medeiros MI, Rodrigues D, MelloVarani A de, Luo Y, Allard MW, Falcao J. Phylogenetic and antimicrobial resistance

gene analysis of *Salmonella* Typhimurium strains isolated in Brazil by whole genome sequencing. PloS One 2018;13(8):1-16.

Almeida IA de, Peresi JT, Alves EC, Marques DF, Teixeira IS, Lima e Silva SI de, Pigon SR, Tiba MR, Fernandes SA. *Salmonella* Alachua: Causative agent of a foodborne disease outbreak. Braz J Infect Dis 2015;19(3):233–238.

Arias ML, Utzinger D, Antillón F, Glenn E. Natural presence of the bacterium *Salmonella* sp. in hen eggs consumed in Costa Rica. Rev Biol Trop 1996;44(2):891–893.

Asensi GF, Reis EM dos, Del Aguila EM, Rodrigues D, Silva JT, Paschoalin VM. Detection of *Escherichia coli* and *Salmonella* in chicken rinse carcasses. Br Food J 2009;111(6):517–527.

Avila-Vega DE, Álvarez-Mayorga B, Arvizu-Medrano SM, Pacheco-Aguilar R, Martínez-Peniche R, Hernández-Iturriaga M. Microbiological profile and incidence of *Salmonella* and *Listeria monocytogenes* on hydroponic bell peppers and greenhouse cultivation environment. J Food Prot 2014;77(11):1904–1910.

Baptista D, Santos A, Aquino MH, Abreu D, Rodrigues D, Nascimento E, Pereira V. Prevalência e susceptibilidade antimicrobiana de sorotipos de *Salmonella* spp. isolados de frangos vivos e carcaças no estado do Rio de Janeiro. Pesq Vet Bras 2018;38(7):1278–1285.

Barril PA, Soto SA, Jaureguiberry MV, Gottardi G, Bascur I, Leotta GA, Oteiza JM. Microbiological risk characterization in butcher shops from the province of Neuquen, Patagonia Argentina. LWT - Food Sci Technol 2019;107:35–40.

Baú AC, Carvalhal JB, Aleixo JA. Prevalência de *Salmonella* em produtos de frangos e ovos de galinha comercializados em Pelotas, Rs, Brasil. Ciência Rural 2001;31(2):303–307.

Becerril AL, Dublán O, Domínguez-López A, Arizmendi D, Quintero-Salazar B. Hygienic quality of the traditional red chorizo commercialized in the city of Toluca, State of Mexico. Rev Mex Cienc Pecu 2019;10(1):172– 185.

Bello-Pérez LA, Ortiz-Dillanes DM, Pérez-Memije E, Castro-Domínguez V. *Salmonella* en carnes crudas: un estudio en localidades del estado de Guerrero. Salud Publ Mex 1990;32(1):74–79.

Beltrão J, Pereira L, Gonzalez A. (2017). Microbiological analysis and evaluation of Good Manufacturing Practices during the processing of raw white cabbage (*Brassica oleracea* var. *capitata* f. alba) served in a self-service restaurant. Vigil sanit debate 2017;5(4):1-8.

Benetti TM, Monteiro CL, Beux MR, Abrahão WM. (2013). Enzyme-linked imunoassays for the detection of *Listeria* sp. and *Salmonella* sp. in

sausage: A comparison with conventional methods. Braz J Microbiol 2013;44(3):791–794.

Berg RR van der, Dissel S, Rapallini ML, Weijden CC van der, Wit B, Heymans R. Characterization and whole genome sequencing of closely related multidrug-resistant *Salmonella enterica* serovar Heidelberg isolates from imported poultry meat in the Netherlands. PLoS ONE 2019;14(7):1–20.

Bersot L, Viana C, Sereno M, Perin AP, Barcellos V. Occurrence of *Salmonella* sp. In poultry carcasses evaluated from the retail trade between 2007 and 2013 in Paraná State, Brazil. Braz J Vet Res An Sci 2019;56(2):1-7.

Bersot L, Cavicchioli V, Viana C, Burin RC, Camargo AC, Almeida J, Nero LA, Destro MT. Prevalence, antimicrobial resistance, and diversity of *Salmonella* along the pig production chain in Southern Brazil. Pathogens 2019;8(204):1–10.

Betancor L, Pereira M, Martinez A, Giossa G, Fookes M, Flores K, Barrios P, Repiso V, Vignoli R, Cordeiro N, Algorta G, Thomson N, Maskell D, Schelotto F, Chabalgoity JA. Prevalence of *Salmonella enterica* in poultry and eggs in Uruguay during an epidemic due to *Salmonella enterica* serovar Enteritidis. J Clin Microbiol 2010;48(7):2413–2423.

Betancor L, Schelotto F, Martinez A, Pereira M, Algorta G, Rodríguez MA, Vignoli R, Chabalgoity JA. Random amplified polymorphic DNA and phenotyping analysis of *Salmonella enterica* serovar Enteritidis isolates collected from humans and poultry in Uruguay from 1995 to 2002. J Clin Microbiol 2004;42(3):1155–1162.

Bier D, Kich JD, Duarte SC, Silva MR, Valsoni LM, Ramos CA, Rodrigues DP, Araújo F. Survey of *Salmonella* spp. in beef meat for export at slaughterhouses in Brazil. Pesq Vet Bras 2018;38(11):2037–2043.

Borowsky LM, Schmidt V, Cardoso M. Estimation of most probable number of *Salmonella* in minced pork samples. Braz J Microbiol 2007;38(3):544–546.

Boscán LA, Arzálluz AM, Ugarte CI, Sánchez D, Díaz D, Wittum TE, Hoet AE. Isolation of *Salmonella*s with zoonotic importance in viscera from broiler chickens in Zulia State, Venezuela. Revista Científica FCV-LUZ 2005;15(6):576–582.

Bosilevac JM, Guerini MN, Brichta-Harhay DM, Arthur TM, Koohmaraie M. Microbiological characterization of imported and domestic boneless beef trim used for ground beef. J Food Prot 2007;70(2):440–449.

Cabral C, Conte-Junior C, Silva J, Paschoalin V. *Salmonella* spp. contamination in fresh pork and chicken sausages marketed in Niterói and Rio de Janeiro, Brazil. J Verbrauch Lebensm 2014;9(3):243–249.

Cabral C, Panzenhagen PH, Delgado K, Silva G, Rodrigues D, Franco R, Conte-Junior C. Contamination of carcasses and utensils in small swine slaughterhouses by *Salmonella* in the northwestern region of the state of Rio de Janeiro, Brazil. J Food Prot 2017;80(7):1128–1132.

Cabrera-Diaz E, Barbosa-Cardenas CM, Perez-Montaño JA, Gonzalez-Aguilar D, Pacheco-Gallardo C, Barba J. Occurrence, serotype diversity, and antimicrobial resistance of *Salmonella* in ground beef at retail stores in Jalisco State, Mexico. J Food Prot 2013;76(12):2004–2010.

Campoverde AD. (2015). *Evaluación microbiológica de Escherichia coli y Salmonella en embutidos artesanales (chorizo y morcilla) expendidos en los mercados de la ciudad de Tulcán*. Universidad Politécnica Estatal del Carchi. Retrieved from http://repositorio.upec.edu.ec/handle/123456789/357

Cardoso M, Ribeiro AR, Santos L dos, Pilotto F, Moraes HL de, Salle CT, Rocha SL, Nascimento V do. Antibiotic resistance in *Salmonella* Enteritidis isolated from broiler carcasses. Braz J Microbiol 2006;37(3):368–371.

Carvalho AC, Cortez AL. *Salmonella* spp. em carcaças, carne mecanicamente separada, lingüiças e cortes comerciais de frango. Ciência Rural 2005;35(6):1465–1468.

Carvalho SV, Rogovski P, Cadamuro R, Viancelli A, Michelon W, Reis D dos, Chagas I das, Assenço R, Lanna MC, Treichel H, Fongaro G. Co-contamination of food products from family farms in an environmental disaster area in Southeast Brazil with pathogenic bacteria and enteric viruses. Arch Virol 2019;165(3)715–718.

Castagna SM, Muller M, Macagnan M, Rodenbusch CR, Canal C, Cardoso M. Detection of *Salmonella* sp. from porcine origin: A comparison between a PCR method and standard microbiological techniques. Braz J Microbiol 2005;36:373–377.

Castañeda-Ramírez C, Cortes-Rodríguez V, Fuente-Salcido N de la, Bideshi DK, Rincón-Castro MC del, Barboza-Corona JE. Isolation of *Salmonella* spp. from lettuce and evaluation of its susceptibility to novel bacteriocins of *Bacillus thuringiensis* and antibiotics. J Food Prot 2011;74(2):274–278.

Castillo A, Villarruel-López A, Navarro-Hidalgo V, Martínez-González NE, Torres-Vitela MR. *Salmonella* and *Shigella* in freshly squeezed orange juice, fresh oranges, and wiping cloths collected from public markets and street booths in Guadalajara, Mexico: Incidence and comparison of analytical routes. J Food Prot 2006;69(11):2595–2599.

Castro-Rosas J, Gómez-Aldapa CA, Acevedo-Sandoval OA, González CA, Villagomez-Ibarra JR, Chavarría N, Villarruel-López A, Torres-Vitela MR. Frequency and behavior of *Salmonella* and *Escherichia coli* on whole and sliced jalapeño and serrano peppers. J Food Prot 2011;74(6):874–881.

Castro-Rosas J, Santos EM, Gómez-Aldapa CA, González CA, Villagomez-Ibarra JR, Gordillo-Martínez AJ, Villarruel A, Torres-Vitela MR. Incidence and behavior of *Salmonella* and *Escherichia* coli on whole and sliced zucchini squash (*Cucurbita pepo*) fruit. J Food Prot 2010;73(8):1423–1429.

Cavalin PB, Sarmiento JJ, Kobayashi RK, Nakazato G, Ocaña A, Oliveira TC. Detection of *Salmonella* spp. and diarrheagenic *Escherichia coli* in fresh pork sausages. Semin Cienc Agrar 2018;39(4):1533–1545.

Chaves BD and Brashears MM. Prevalence of molecular markers for *Salmonella* and Shiga toxigenic *Escherichia coli* (STEC) in whole-muscle beef cuts sold at retail markets in Costa Rica. Food Control 2014;50:497-501.

Chávez-Martínez A, Paredes-Montoya P, Rentería-Monterrubio AL, Corral-Luna A, Lechuga-Valles R, Dominguez-Viveros J, Sánchez-Vega R, Santellano-Estrada E. Microbial quality and prevalence of foodborne pathogens of cheeses commercialized at different retail points in Mexico. Food Sci Technol 2019;39:703–710.

Colello R, Ruiz MJ, Padin VM, Rogé AD, Leotta G, Padola NL, Etcheverría AI. (2018). Detection and characterization of *Salmonella* serotypes in the production chain of two pig farms in Buenos Aires Province, Argentina. Front Microbiol 2018;9,1370.

Corbellini LG, Júnior A, Costa E, Duarte AS, Albuquerque E, Kich J, Cardoso M, Nauta M. Effect of slaughterhouse and day of sample on the probability of a pig carcass being *Salmonella*-positive according to the *Enterobacteriaceae* count in the largest Brazilian pork production region. Int J Food Microbiol 2016;228:58–66.

Cordano AM, Virgilio R. Evolution of drug resistance in *Salmonella* Panama isolates in Chile. Antimicrob Agents Chemother 1996;40(2):336-341.

Cortes D, Rodríguez V, Verjan N. Phenotypic and genotypic antibiotic resistance of *Salmonella* from chicken carcasses marketed at Ibague, Colombia. Revista Brasileira de Ciencia Avicola 2017;19(2):347–354.

Cossi MV, Almeida M de, Dias M, Pinto PS, Nero LA. Inspected and non-inspected chilled chicken carcasses commercialized in Viçosa, MG, Brazil: microbiological parameters and *Salmonella* spp. occurrence. Ciência Rural 2012;42(9):1675–1681.

Cossi MV, Burin RC, Camargo AC, Dias M, Lanna FG, Pinto PS, Nero LA. Low occurrence of *Salmonella* in the beef processing chain from Minas Gerais state, Brazil: From bovine hides to end cuts. Food Control 2014;40(1):320–323.

Costa M, Cruz AI, Bispo AS, Ferreira M, Costa J, Evangelista-Barreto NS. Occurrence and antimicrobial resistance of bacteria in retail market spices. Ciencia Rural 2020;50(4):1–7.

Cruz M da, Leite YJ, Marques J, Pavelquesi SL, Oliveira L, Silva IC da, Orsi D. Microbiological quality of minimally processed vegetables commercialized in Brasilia, DF, Brazil. Food Sci Technol 2019;39:1-6.

Cunha-Neto A da, Carvalho L, Carvalho RC, Rodrigues D, Mano S, Figueiredo EE, Conte-Junior C. *Salmonella* isolated from chicken carcasses from a slaughterhouse in the state of Mato Grosso, Brazil: antibiotic resistance profile, serotyping, and characterization by repetitive sequence-based PCR system. Poult Sci 2018;97(4):1373–1381.

Curi de Montbrun S, Blythman HE, Giménez DF. *Salmonella* en bovinos faenados. Boletìn de La Oficina Sanitaria Panamericana 1972:50–57. Retrieved from https://iris.paho.org/handle/10665.2/10909

Dias M, Cavicchioli V, Camargo AC, Lanna FG, Pinto PS, Bersot L, Nero LA. Molecular tracking of *Salmonella* spp. in chicken meat chain: from slaughterhouse reception to end cuts. J. Food Sci. Technol 2016;53(2):1084–1091.

Díaz MÁ, Díaz PL, Rodríguez EC, Montaño LA, Gartner DM, Vernaza ME, Eljach V, Realpe ME. Brote de *Salmonella* Enteritidis resistente a ácido nalidíxico en Popayán, Cauca, 2011. Biomédica 2013;33(1):62-69.

Díaz MÁ, Díaz PL, Rodríguez EC, Montaño LA, Medina MI, González GI, Realpe ME. Caracterización fenotípica y genotípica de *Salmonella* Typhimurium variante 5- asociada a un brote de enfermedad transmitida por alimentos en el municipio de Paz de Río, Boyacá, 2010. Iatreia 2014;27(1):23–30.

Donado-Godoy P, Byrne BA, León M, Castellanos R, Vanegas C, Coral A, Arevalo A, Clavijo V, Vargas M, Romero JJ, Tafur MA, Pérez-Gutierrez E, Smith W. Prevalence, resistance patterns, and risk factors for antimicrobial resistance in bacteria from retail chicken meat in Colombia. J Food Prot 2015;78(4):751–759.

Donado-Godoy P, Clavijo V, León M, Tafur MA, Gonzales S, Hume M, Alali W, Walls I, Lo Fo Wong DM, Doyle MP. Prevalence of *Salmonella* on retail broiler chicken meat carcasses in Colombia. J Food Prot 2012;75(6):1134-1138.

Donado-Godoy P, Clavijo V, León M, Arevalo A, Castellanos R, Bernal J, Tafur M, Ovalle MV, Alali WQ, Romero-Zuñiga JJ, Walls I, Doyle

MP. Counts, serovars, and antimicrobial resistance phenotypes of *Salmonella* on raw chicken meat at retail in Colombia. J Food Prot 2014;77(2):227–235.

Escartin EF, Castillo A, Hinojosa-Puga A, Saldaña-Lozano J. Prevalence of *Salmonella* in chorizo and its survival under different storage temperatures. Food Microbiol 1999;16(5):479–486.

Espinal P, Prieto E, Otero V, Máttar S. Presencia del gen de invasividad *inv* A en cepas de *Salmonella* spp. aisladas de alimentos del Caribe Colombiano. Rev Cub Salud Pública 2006;32(2)115-120.

Espinoza-Medina IE, Rodríguez-Leyva FJ, Vargas-Arispuro I, Islas-Osuna MA, Acedo-Félix E, Martínez-Téllez MA. PCR identification of *Salmonella*: Potential contamination sources from production and postharvest handling of cantaloupes. J Food Prot 2006;69(6):1422–1425.

Estrada-Garcia T, Lopez-Saucedo C, Zamarripa-Ayala B, Thompson MR, Gutierrez-Cogco L, Mancera-Martinez A, Escobar-Gutierrez A. Prevalence of *Escherichia coli* and *Salmonella* spp. in street-vended food of open markets (tianguis) and general hygienic and trading practices in Mexico City. Epidemiol Infect 2004;132(6):1181–1184.

Evêncio-Luz L, Lima-Filho JV, Evêncio-Neto J. Occurrence of *Salmonella* sp. and coagulase-positive staphylococci in raw eggs and coalho cheese: Comparative study between two cities of Brazil's Northeast. Braz J Microbiol 2012;43(4):1463–1466.

Fai AE, de Figueiredo EA, Verdin SE, Pinheiro NM, Braga AR, Stamford TL. *Salmonella* sp. e *Listeria monocytogenes* em presunto suíno comercializado em supermercados de Fortaleza (CE, Brasil): fator de risco para a saúde pública. Cien Saude Colet 2011;16(2):657–662.

Favier GI, Lucero CSM, Lazarte V, Escudero ME. Prevalence, antimicrobial susceptibility, and molecular characterization by PCR and pulsed field gel electrophoresis (PFGE) of *Salmonella* spp. isolated from foods of animal origin in San Luis, Argentina. Food Control 2013;29(1):49–54.

Fernandes EF, Paulino AA, Fernandes MF, Moura AP, Mota RA. Qualidade microbiológica da carne de ovinos (*Ovis aries*) comercializada nos mercados públicos do Recife-PE. Med Vet 2009;3(4):7–12.

Fernandes SA, Paterson DL, Ghilardi-Rodrigues ÂC, Adams-Haduch JM, Tavechio AT, Doi Y. CTX-M-2-producing *Salmonella* Typhimurium isolated from pediatric patients and poultry in Brazil. Microb Drug Resist 2009;15(4):317–321.

Ferreira LC, Junqueira RG. Microbiological evaluation of pequi (*Caryocar brasiliense* Camb.) preserves made from a typical Brazilian fruit.

World J Microbiol Biotechnol 2007;23:1179–1181.

Forero Y, Galindo M, Ramírez G. Patógenos asociados a enfermedades transmitidas por alimentos en restaurantes escolares de Colombia. Rev Chil Nutr 2017;44(4):325-332

Freire BC, Melo EC de, Araújo N de, Rabelo JL, Soares KM. Microbiological characterization of vacuum-packed and conventionally packed sliced turkey hams marketed in Mossoró, Brazil. Acta Vet Bras 2019;13(1):30–36.

Freitas Neto OC de, Galdino VM, Campello PL, Almeida AM de, Fernandes SA, Berchieri Junior A. *Salmonella* serovars in laying hen flocks and commercial table eggs from a region of São Paulo State, Brazil. R Bras Ci Avíc 2014;16(2):57–62.

Fröder H, Martins CG, de Souza K, Landgraf M, Franco B, Destro MT. (2007). Minimally processed vegetable salads: Microbial quality evaluation. J Food Prot 2007;70(5):1277-1280.

Gallegos-Robles MA, Morales-Loredo A, Alvarez-Ojeda G, Vega-P A, Chew-M Y, Velarde S, Fratamico P. Identification of *Salmonella* serotypes isolated from cantaloupe and chile pepper production systems in Mexico by PCR-restriction fragment length polymorphism. J Food Prot 2008;71(11):2217–2222.

Galvão J, Biondo A, Possebon F, Spina TL, Correia L, Zuim C, Filho J, Pantoja C, Almeida Nogueira J de. Microbiological vulnerability of eggs and environmental conditions in conventional and free-range housing syste*m*s. Semin Cienc Agrar 2018;39(1):133–142.

Gecan JS, Bandler R, Staruszkiewicz WF. Fresh and frozen shrimp: A profile of filth, microbiological contamination, and decomposition. J Food Prot 1994;57(2):154–158.

Gómez-Aldapa CA, Gutiérrez-Alcántara EJ, Torres-Vitela MR, Rangel-Vargas E, Villarruel-López A, Castro-Rosas J. Prevalence and behavior of multidrug-resistant *Salmonella* strains on raw whole and cut nopalitos (*Opuntia ficus-indica* L.) and on nopalitos salads. J Sci Food Agric 2017;97(12):4117–4123.

Gómez-Aldapa CA, Rangel-Vargas E, Bautista-De León H, Castro-Rosas J. Presence of non-O157 Shiga toxin-producing *Escherichia coli*, enterotoxigenic *E. coli*, enteropathogenic *E. coli* and *Salmonella* in fresh beetroot (*Beta vulgaris* L.) juice from public markets in Mexico. J Sci Food Agric 2014;94(13):2705–2711.

Gómez-Aldapa CA, Rangel-Vargas E, Castro-Rosas J. Frequency and correlation of some enteric indicator bacteria and *Salmonella* in ready-to-eat raw vegetable salads from Mexican restaurants. J Food Sci 2013;78(8):1201–1207.

Gómez-Aldapa CA, Rangel-Vargas E, Cruz AM, Román-Gutiérrez AD, Castro-Rosas J. (2013). Presence of coliform bacteria, faecal coliforms, *Escherichia coli* and *Salmonella* on corn tortillas in central Mexico. Food Control 2013;32(1):31–34.

Gómez-Gamboa L, Bermúdez-González J, Medina Z, López M, Navarro J, Morales E. Diversidad de serotipos de *Salmonella* en camarones de cultivo crudos congelados (*Litopeneaus vannamei*) de Venezuela. Rev Soc Ven Microbiol 2012;32(1):22–28.

Gonzalez F, Araque M. Molecular typing, antibiotic resistance profiles and biocide susceptibility in *Salmonella enterica* serotypes isolated from raw chicken meat marketed in Venezuela. Germs 2019;9(2):81–88.

Gutiérrez-Alcántara EJ, Gómez-Aldapa CA, Román-Gutiérrez AD, Rangel-Vargas E, González-Olivares LG, Castro-Rosas J. Antimicrobial activity of roselle *Hibiscus Sabdariffa* calyx extracts on culture media and carrots against multidrug-resistant *Salmonella* strains isolated from raw carrots. J Food Saf 2016;36(4):450–458.

Guzmán-Gómez G, Ayala MA, Cabrera-Díaz E, Pérez-Montaño JA, Muñoz-Valle JF, Torres-Vitela MR, Ruiz-Quezada SL. Frequency of *Salmonella* and *Listeria monocytogenes* in five commercial brands of chicken eggs using a combined method of enrichment and nested-PCR. J Food Prot 2013;76(3):429–434.

Guzman-Hernandez R, Contreras-Rodriguez A, Hernandez-Velez R, Perez-Martinez I, Lopez-Merino A, Zaidi MB, Estrada-Garcia T. Mexican unpasteurised fresh cheeses are contaminated with *Salmonella* spp., non-O157 Shiga toxin producing *Escherichia coli* and potential uropathogenic *E. coli* strains: A public health risk. Int J Food Microbiol 2016;237:10–16.

Harvey RWS, Price TH. A survey of Argentine and Lebanese bone for *Salmonella*s with particular reference to the isolation of *Salmonella typhimurium*. J Appl Bacteriol 1978;44(2):241–247.

Heredia N, García S, Rojas G, Salazar L. Microbiological condition of ground meat retailed in Monterrey, Mexico. J Food Prot 2001;64(8):1249–1251.

Hernandez T, Sierra A, Rodriguez-Alvarez C, Torres A, Arevalo MP, Calvo M, Arias A. *Salmonella enterica* serotypes isolated from imported frozen chicken meat in the Canary Islands. J Food Prot 2005;68(12):2702–2706.

Hofer E, Zamora MR, Lopes AE, Moura AM de, Araújo H de, Leite J, Leite MD, da Silva Filho S. Sorovares de *Salmonella* em carne de eqüídeos abatidos no nordeste do Brasil. Pesqui Vet Bras 2000;20(2):80–84.

Jiménez SM, Salsi MS, Tiburzi MC, Pirovani ME. A comparison between broiler chicken carcasses with and without visible faecal

contamination during the slaughtering process on hazard identification of *Salmonella* spp. *J Appl Microbiol*, *93*(4), 593–598.

Junod T, López-Martin J, Gädicke P. Estudio de susceptibilidad antimicrobiana de *Salmonella enterica* en muestras de origen animal y alimentario. Rev Méd Chile 2013;141:298–304.

Karczmarczyk M, Martins M, McCusker M, Mattar S, Amaral L, Leonard N, Aarestrup FM, Fanning S. Characterization of antimicrobial resistance in *Salmonella enterica* food and animal isolates from Colombia: Identification of a *qnrB19*-mediated quinolone resistance marker in two novel serovars. FEMS Microbiol Lett 2010;313(1):10–19.

Kich JD, Coldebella A, Morés N, Nogueira M, Cardoso M, Fratamico PM, Call J, Fedorka-Cray P, Luchansky JB. Prevalence, distribution, and molecular characterization of *Salmonella* recovered from swine finishing herds and a slaughter facility in Santa Catarina, Brazil. Int J Food Microbiol 2011;151(3)307–313.

Kottwitz L, Leão JA, Back A, Rodrigues D, Magnani M, de Oliveira T. Commercially laid eggs vs. discarded hatching eggs: Contamination by *Salmonella* spp. Braz J Microbiol 2013;44(2):367–370.

Kottwitz LB, Scheffer MC, Dalla-Costa LM, Farah SM, Moscalewski WS, Magnani M, Oliveira TC de. Molecular characterization and resistance profile of *Salmonella* Enteritidis PT4 and PT9 strains isolated in Brazil. Journal of Medical Microbiology 2011;60(7):1026–1031.

Kuri V, Madden RH, Collins MA. Hygienic quality of raw pork and chorizo (raw pork sausage) on retail sale in Mexico City. J Food Prot 1996;59(2):141–145.

Lapierre L, Cornejo J, Zavala S, Galarce N, Sánchez F, Benavides MB, Guzmán M, Sáenz L. Phenotypic and genotypic characterization of virulence factors and susceptibility to antibiotics in *Salmonella* Infantis strains isolated from chicken meat: First findings in Chile. Animals 2020;10(6):1–15.

Leiva A, Molina A, Redondo-Solano M, Artavia G, Rojas-Bogantes L, Granados-Chinchilla F. Pet food quality assurance and safety and quality assurance survey within the costa rican pet food industry. Animals 2019;9(11):1-25.

Lima B, Canto AC, Nascimento R, Franco R, Nascimento ER. Prevalência de *Salmonella* spp. na superfície no interior de linguiça frescal suína comercializada no Município de Niterói, Rio de Janeiro, Brasil. Rev Bras Med Vet 2011;33(3):133–136.

Lima E de, Pinto PS, Santos J dos, Vanetti MC, Bevilacqua P, Almeida L de, Pinto M, Dias, F. Isolamento de *Salmonella* sp e *Staphylococcus*

aureus no processo do abate suíno como subsídio ao sistema de Análise de Perigos e Pontos Críticos de Controle - APPCC. Pesqui Vet Bras 2004;24(4):185–190.

Loayza SP. (2011). *Control de calidad de la carne de bovino en el mercado municipal de la ciudad de Piñas Provincia de El Oro*. Universidad Nacional de Loja. Retrieved from https://dspace.unl.edu.ec/jspui/bitstream/123456789/5387/1/tesis de control de calidad de carne. Santiago Loayza.pdf

Loiko, M. R., de Paula, C. M. D., Langone, A. C. J., Rodrigues, R. Q., Cibulski, S., Rodrigues, R. de O., … Tondo, E. C. (2016). Genotypic and antimicrobial characterization of pathogenic bacteria at different stages of cattle slaughtering in southern Brazil. *Meat Sci*, *116*, 193–200.

Lopes GV, Pissetti C, Pellegrini D, Silva LE da, Cardoso M. Resistance phenotypes and genotypes of *Salmonella enterica* subsp. *enterica* isolates from feed, pigs, and carcasses in Brazil. J Food Prot 2015;78(2):407–413.

Luiz A, Moreira F, Corrêa E, Falcão D. Monitoring of the dissemination of *Salmonella* in the chicken Frankfurt-sausage production line of a sausage factory in the state of São Paulo, Brazil. Mem Inst Oswaldo Cruz 2004;99(5):477–480.

Maffei DF, Moreira DA, Silva MB, Faria DB, Saldaña E, Ishimura I, Landgraf M, Franco BD. Assessing the relationship between organic farming practices and microbiological characteristics of organic lettuce varieties (*Lactuca sativa* L.) grown in Sao Paulo, Brazil. J Appl Microbiol 2019;127(1):237–247.

Maradiaga M, Miller MF, Thompson L, Pond A, Gragg SE, Echeverry A, Garcia LG, Loneragan GH, Brashears MM. *Salmonella* in beef and produce from honduras. J Food Prot 2015;78(3):498–502.

Marinheiro M, Ghizzi L, Cereser N, Lima H de, Timm C. Qualidade microbiológica de queijo mussarela em peça e fatiado. Semin Cienc Agrar 2015;36(3):1329–1334.

Martínez-Chávez L, Cabrera-Diaz E, Pérez-Montaño JA, Garay-Martínez LE, Varela-Hernández JJ, Castillo A, Lucia L, Ávila-Novoa MG, Cardona-López MA, Gutiérrez-González P, Martínez-Gonzáles NE. Quantitative distribution of *Salmonella* spp. and *Escherichia coli* on beef carcasses and raw beef at retail establishments. Int J Food Microbiol 2015;210:149-155.

Martínez A, Villoch A, Ribot A, Ponce P. Evaluación de la calidad e inocuidad de quesos frescos artesanales de tres regiones de una provincia de Cuba. Rev. Salud Anim 2013;35(3):210–213.

Martínez MM, Gómez CA. Calidad composicional e higiénica de la leche cruda recibida en industrias lácteas de Sucre, Colombia. Biotecnología en el Sector Agropecuario y Agroindustrial 2013;11(2)93–100.

Mattiello SP, Drescher G, Barth VC, Ferreira CA, Oliveira SD. (2015). Characterization of antimicrobial resistance in *Salmonella enterica* strains isolated from Brazilian poultry production. Anton Leeuw Int J G 2015;108(5):1227–1238.

Mba-Jonas A, Culpepper W, Hill T, Cantu V, Loera J, Borders J, Saathoff-Huber L, Nsubuga J, Zambrana I, Dalton S, Williams I, Neil KP. A multistate outbreak of human *Salmonella* Agona infections associated with consumption of fresh, whole papayas imported from Mexico - United States, 2011. Clin Infect Dis 2018;66(11):1756–1761.

Medeiros MA, de Oliveira DC, Rodrigues D, de Freitas DR. Prevalence and antimicrobial resistance of *Salmonella* in chicken carcasses at retail in 15 Brazilian cities. Pan Am J Public Health 2011;30(6):555–560.

Mejía L, Medina JL, Bayas R, Satan C, Villavicencio F, Zapata S, Matheu J, Wagenaar JA, González-Candelas F, Vinueza-Burgos C. Genomic epidemiology of *Salmonella* Infantis in Ecuador: From poultry farms to human infections. Front Vet Sci 2020;7:1–10.

Mejia L, Vela G, Zapata S. High occurrence of multiresistant *Salmonella* Infantis in retail meat in Ecuador. Foodborne Path Dis 2020;18(1):41–48.

Melo RT, Guimarães AR, Mendonça EP, Coelho LR, Monteiro GP, Fonseca BB, Rossi DA. Identifição sorológica e relação filogenética de *Salmonella* spp. de origem suína. Pesq Vet Bras 2011;31(12):1039–1044.

Mendonça EP, Melo RT, Oliveira MR, Monteiro GP, Peres PA, Fonseca BB, Giombelli A, Rossi DA. Characteristics of virulence, resistance and genetic diversity of strains of *Salmonella* Infantis isolated from broiler chicken in Brazil. Pesq Vet Bras 2020;40(1):29–38.

Michael GB, Cardoso M, Rabsch W, Schwarz S. Phenotypic and genotypic differentiation of porcine *Salmonella enterica* subsp. *enterica* serovar Derby isolat*e*s. Vet Microbiol 2006;118(3–4):312–318.

Michael GB, Cardoso M, Schwarz S. Molecular analysis of *Salmonella enterica* subsp. *enterica* serovar Agona isolated from slaughter pigs. Vet Microbiol 2006;112(1):43–52.

Michael GB, Cardoso M, Schwarz S. (2008). Molecular analysis of multiresistant porcine *Salmonella enterica* subsp. *enterica* serovar Bredeney isolates from Southern Brazil: identification of resistance genes, integrons and a group II intron. Int J Antimicrob Agents 2008;*32*(2):120–129.

Minharro S, Nascimento C, Galletti J, Merisse T, Feitosa A, Santos H, Dias F, Santana E, Baldani C, Andrade M. Antimicrobial susceptibility of *Salmonella* serovars isolated from edible offal and carcasses of slaughtered poultry in the state of Tocantins, Brazil. Semin Cienc Agrar 2015;36(4):2661–2669.

Miranda JM, Mondragón AC, Martinez B, Guarddon M, Rodriguez JA. Prevalence and antimicrobial resistance patterns of *Salmonella* from different raw foods in Mexico. J Food Prot 2009;72(5):966–971.

Mogollón DC, Rodríguez VE, Verjan N. Prevalence and molecular identification of *Salmonella* spp. isolated from commercialized eggs at Ibague, Colombia. Rev Salud Anim 2016;38(3):164–172.

Molina A, Granados-Chinchilla F, Jiménez M, Acuña-Calvo MT, Alfaro M, Chavarría G. Vigilance for *Salmonella* in feedstuffs available in Costa Rica: Prevalence, serotyping and tetracycline resistance of isolates obtained from 2009 to 2014. Foodborne Path Dis 2015;13(3)119–127.

Monte DF, Lincopan N, Berman H, Cerdeira L, Keelara S, Thakur S, Fedorka-Cray PJ, Landgraf M. Genomic features of high-priority *Salmonella* enterica serovars circulating in the food production chain, Brazil, 2000-2016. Sci Rep 2019;9(1):11058.

Monteiro E, Costa P da, Manfrin L, Freire D, Silva IC da, Orsi D. Qualidade microbiológica de carne bovina moída comercializada em supermercados do Distrito Federal, Brasil. Rev Bras Hig Sanid Anim 2018;12(4):520-530.

Morales-Hernández L, Hernández-Anguiano AM, Cháidez-Quiroz C, Rendón-Sánchez G, Suslow TV. Detección de *Salmonella* spp. en melón cantaloupe en unidades de producción y unidad de empaque. Agricultura Técnica en México 2009;35(2):135–145.

Morales G, Blanco L, Arias ML, Chaves C. Evaluación de la calidad bacteriológica de tilapia fresca (*Oreochromis niloticus*) proveniente de la Zona Norte de Costa Rica. Arch Latinoam Nutr 2004;54(4):433-437.

Moreno LZ, Gomes VT, Moreira J, Oliveira CH de, Peres BP, Silva AP, Thakur S, La Ragione RM, Moreno, AM. First report of mcr-1-harboring *Salmonella enterica* serovar Schwarzengrund isolated from poultry meat in Brazil. Diagn Micr Infec Dis 2019;93(4):376–379.

Morillo N, Rondón I, Valero-Leal K, Uzcátegui-Bracho S. Bacterias patógenas en carne de cangrejo comercializado fresco y pasteurizado. Maracaibo, Venezuela. Revista Científica FCV-LUZ 2007;17(3):288–293.

Moura MS, Oliveira RP, Melo RT, Mendonça EP, Fonseca BB, Rossi DA. (2014). Genes de virulência e diversidade genética em *Salmonella* spp. isoladas de amostras de origem suína. Arq Bras Med Vet Zootec 2014;66(5):1367–1375.

Moura Q, Fernandes MR, Cerdeira L, Ienne S, Souza TA, Negrão FJ, Lincopan N. Draft genome sequence of a multidrug-resistant CMY-2-producing *Salmonella enterica* subsp. *enterica* serovar Minnesota ST3088 isolated from chicken meat. J Glob Antimicrob Resist 2017;8:67–69.

Muñoz S, Vilca M, Ramos D, Lucas J. Frecuencia de Enterobacterias en verduras de consumo crudo expendidas en cuatro mercados de Lima, Perú. Rev Inv Vet Perú 2013;24(3):300–306.

Mürmann L, Corbellini LG, Collor A, Cardoso M. Quantitative risk assessment for human salmonellosis through the consumption of pork sausage in Porto Alegre, Brazil. J Food Prot 2011;74(4):553–558.

Narváez-Bravo C, Miller MF, Jackson T, Jackson S, Rodas-González A, Pond K, Echeverry A, Brashears, MM. *Salmonella* and *Escherichia coli* O157:H7 prevalence in cattle and on carcasses in a vertically integrated feedlot and harvest plant in Mexico. J Food Prot 2013;76(5):786–795.

Narváez-Bravo C, Rodas-González A, Fuenmayor Y, Flores-Rondon C, Carruyo G, Moreno M, Perozo-Mena A, Hoet AE. *Salmonella* on feces, hides and carcasses in beef slaughter facilities in Venezuela. Int J Food Microbiol 2013;166(2):226–230.

Narváez CA, Parra KC, Huerta-Leidenz N, Rodas-González A, Moreno LA de. Aislamiento de *Salmonella* y *Escherichia coli* patógenas durante el procesamiento de hamburguesas en una pequeña planta de Maracaibo, Venezuela. Revista Cientifica FCV-LUZ 2005;15(6):551–559.

Nascimento MS, Carminati JA, Silva IC, Silva DL, Bernardi AO, Copetti MV. *Salmonella*, *Escherichia coli* and *Enterobacteriaceae* in the peanut supply chain: From farm to table. Food Res Int 2018;105:930–935.

Nayarit-Ballesteros N, Rubio-Lozano MS, Delgado-Suárez E, Méndez-Medina D, Braña-Varela D, Rodas-Suárez O. Perfil de resistencia a antibióticos de serotipos de *Salmonella* spp. aislados de carne de res molida en la Ciudad de México. Salud Publ Mex 2016;58(3):371–377.

Neitzke, DC, Roza C da, Hart F. Segurança dos alimentos: contaminação por *Salmonella* sp. no abate de suínos. Braz J Food Technol 2017;20:1-7.

Oliveira S de, Flores F, Santos L dos, Brandelli A. Antimicrobial resistance in *Salmonella enteritidis* strains isolated from broiler carcasses, food, human and poultry-related samples. Int J Food Microbiol 2005;97:297–305.

Oliveira MA de, Souza VM de, Bergamini AM, De Martinis EC. Microbiological quality of ready-to-eat minimally processed vegetables

consumed in Brazil. Food Control 2011;22(8):1400–1403.

Orozco L, Iturriaga MH, Tamplin ML, Fratamico PM, Call JE, Luchansky JB, Escartin EF. Animal and environmental impact on the presence and distribution of *Salmonella* and *Escherichia coli* in hydroponic tomato greenhouses. J Food Prot 2008;71(4):676–683.

Orozco L, Rico-Romero L, Escartín EF. Microbiological profile of greenhouses in a farm producing hydroponic tomatoes. J Food Prot 2008;71(1):60–65.

Padilha MR, Fernandes Z, Leal TC, Leal NC, Almeida AM de. Pesquisa de bactérias patogênicas em leite pasteurizado tipo C comercializado na cidade do Recife, Pernambuco, Brasil. Rev Soc Bras Med Trop 2001;34(2):167–171.

Paim D, Pissetti C, Vieira TR, Werlang G, Freitas Costa E de, Kich J, Cardoso M. (2019). Enumeration, antimicrobial resistance and typing of *Salmonella enterica*: Profile of strains carried in the intestinal contents of pigs at slaughter in Southern Brazil. Acta Sci Vet 2019;47:1636.

Penha RA, Ferreira JC, Kanashiro AM, Berchieri A, Darini AL. Emergent multidrug-resistant nontyphoidal *Salmonella* serovars isolated from poultry in Brazil coharboring blaCTX-M-2 and qnrB or blaCMY-2 in large plasmids. Diagn Micr Infec Dis 2019;95(1):93–98.

Perez-Montaño JA, Gonzalez-Aguilar D, Barba J, Pacheco-Gallardo C, Campos-Bravo CA, Garcia S, Heredia NL, Cabrera-Diaz E. Frequency and antimicrobial resistance of *Salmonella* serotypes on beef carcasses at small abattoirs in Jalisco State, Mexico. J Food Prot 2012;75(5):867–873.

Perin AP, Martins B, Barreiros MA, Yamatogi R, Nero LA, Bersot L. Occurrence, quantification, pulse types, and antimicrobial susceptibility of *Salmonella* sp. isolated from chicken meat in the state of Paraná, Brazil. Braz J Microbiol 2019;51(1):335–345.

Plaza-Ibarra LA, Morales MF. (2001). *Análisis Microbiológico en Quesos Frescos que se Expenden en Presencia o Ausencia de Listeria y Salmonella. Repositorio de la Escuela Superior Politécnica del Litoral*. Escuela Superior Politècnica del Litoral (ESPOL). Retrieved from https://www.dspace.espol.edu.ec/bitstream/123456789/24428/1/resumen luis plaza.pdf

Procura F, Bueno DJ, Bruno SB, Rogé AD. Prevalence, antimicrobial resistance profile and comparison of methods for the isolation of *Salmonella* in chicken liver from Argentina. Food Res Int 2017;119:541–546.

Puig Y, Espino M, Leyva V, Aportela N, Machín M, Soto P. Serovariedades y patrones de susceptibilidad a los antimicrobianos de cepas de *Salmonella* aisladas de alimentos en Cuba. Pan Am J Public Health 2011;30(6):561–565.

Queiroz M, Rossi BF, Castilho I, Rall VL. (2018). Hygienic-sanitary quality of Minas fresh cheese sold in the city of Botucatu, São Paulo. Arq Inst Biol 2018;84:–6.

Quiñones-Ramírez EI, Vázquez-Salinas C, Pedroche FF, Moreno-Sepúlveda L, Rodas-Suárez OR. Presencia de los géneros *Vibrio* y *Salmonella*, y detección de coliformes faecales en almejas del Golfo de México. Hidrobiológica 2000;10(2):131–138.

Quintana-Ospina G, Holguin-Cespedes G, Rodriguez-Rodriguez V, Verjan-Garcia N. Detection of *Salmonella* spp. antigens in Tolima poultry products by Western Blot. Veterinaria y Zootecnia 2018;12(1):72–83.

Quiroz-Santiago C, Rodas-Suárez OR, Vázquez CR, Fernández FJ, Quiñones-Ramírez EI, Vázquez-Salinas C. Prevalence of *Salmonella* in vegetables from Mexico. J Food Prot 2009;72(6):1279–1282.

Rall VL, Martin JG, Candeias JM, Cardoso KF, Silva M da, Rall R, Araújo Júnior J. Pesquisa de *Salmonella* e das condições sanitárias em frangos e lingüiças comercializados na cidade de Botucatu. Braz J Vet Res An Sci 2009;46(3):167-174.

Ramírez-Hernández A, Varón-García A, Sánchez-Plata MX. Microbiological profile of three commercial poultry processing plants in Colombia. J Food Prot 2017;80(12):1980–1986.

Rangel-Vargas E, Gómez-Aldapa CA, Torres-Vitela MR, Villarruel-López A, Gordillo-Martínez AJ, Castro-Rosas J. Presence and correlation of some enteric indicator bacteria, diarrheagenic *Escherichia coli* pathotypes, and *Salmonella* serotypes in alfalfa sprouts from local retail markets in Pachuca, Mexico. J Food Prot 2015;78(3):609–614.

Rau RB, Lima-Morales D de, Wink PL, Ribeiro AR, Barth AL. *Salmonella enterica mcr-1* positive from food in Brazil: Detection and characterization. Foodborne Path Dis 2020;17(3):202-208.

Regalado-Pineda ID, Rodarte-Medina R, Resendiz-Nava CN, Saenz-Garcia CE, Castañeda-Serrano P, Nava GM. Three-year longitudinal study: Prevalence of *Salmonella enterica* in chicken meat is higher in supermarkets than wet markets from Mexico. Foods 2020;9(3):1-10.

Reges JT, Borges AC, Silva CJ da, Santos S dos, Costa AC, Tavares W, Jesus M de, Silva S da. Qualidade microbiológica e físico química do queijo mussarela a granel comercializadas em Jataí (Goiás, Brasil). Rev Colomb Investig Agroindustriales 2017;4:69-77.

Rengel A, Mendoza S. (1984). Isolation of *Salmonella* from raw chicken in Venezuela. J Food Prot 1984;47(3):213–216.

Reuben A, Treminio H, Arias ML, Chaves C. Presencia de *Escherichia coli* O157:H7, *Listeria monocytogenes* y *Salmonella* spp. en alimentos

de origen animal en Costa Rica. Arch Latinoam Nutr 2004;54(1):5-12.

Rezende AC, Crucello J, Moreira R, Silva B, Sant'Ana A. Incidence and growth of *Salmonella enterica* on the peel and pulp of avocado (*Persea americana*) and custard apple (*Annona squamosa*). Int J Food Microbiol 2016;235:10–16.

Ribeiro AR, Kellermann A, Santos LR dos, Bessa M, Nascimento V do. *Salmonella* spp. in raw broiler parts: Occurrence, antimicrobial resistance profile and phage typing of the *Salmonella* Enteritidis isolates. Braz J Microbiol 2007;38(2):296–299.

Ribeiro VB, Andrigheto C, Bersot LS, Barcellos V, Reis EF, Destro MT. Serological and genetic diversity amongst *Salmonella* strains isolated in a salami processing line. Braz J Microbiol 2007;38(1):178–182.

Ribeiro VB, Lincopan N, Landgraf M, Franco BD, Destro MT. Characterization of class 1 integrons and antibiotic resistance genes in multidrug-resistant *Salmonella* enterica isolates from foodstuff and related sources. Braz J Microbiol 2011;42:685–692.

Ristori C, Rowlands RE, Martins C, Barbosa ML, Santos LF dos, Jakabi M, Melo Franco BD de. Assessment of consumer exposure to *Salmonella* spp., *Campylobacter* spp., and shiga toxin-producing *Escherichia coli* in meat products at retail in the city of Sao Paulo, Brazil. Foodborne Path Dis 2017;14(8):447–453.

Rodriguez-Roque SM, Attie-Habelrih MG, Figueroa-Espinosa RA, Thomas LE, Escalona-Pacheco AJ, Báez-Ramírez EA. Análisis microbiológico de muestras de kibbeh crudo revela la presencia de bacterias enteropatógenas. Salud Publ Mex 2018;60(1):105–106.

Rodriguez JM, Rondón IS, Verjan N. Serotypes of *Salmonella* in broiler carcasses marketed at Ibague, Colombia. Rev Bras Cienc Avic 2015;17(4):545–552.

Rodríguez R, Fandiño C, Donado P, Guzmán L, Verjan N. (2015). Characterization of *Salmonella* from commercial egg-laying hen farms in a central region of Colombia. Avian Dis 2015;59(1):57–63.

Rondón-Barragán IA, Arcos E, Mora-Cardona L, Fandiño C. Characterization of *Salmonella* species from pork meat in Tolima, Colombia. Rev Colomb Cienc Pecu 2015;28:74–82.

Rubio MS, Martínez JF, Hernández R, Bonilla C, Méndez RD, Núñez JF, Echeverry A, Brashears M. Detección de *Listeria monocytogenes*, *Salmonella* y *Yersinia enterocolitica* en carne de res en puntos de venta en México. Rev Mex Cienc Pecu 2013;4(1):107–115.

Ruiz-Roldán L, Martínez-Puchol S, Gomes C, Palma N, Riveros M, Ocampo K, Durand D, Ochoa T, Ruiz J, Pons M. Presence of multidrug

resistant *Enterobacteriaceae* and *Escherichia coli* in meat purchased in traditional markets of Lima. Rev Peru Med Exp Salud Publica 2018;35(3):425–432.

Ruschel CK, Carvalho HH, Souza RB de, Tondo EC. Qualidade microbiológica e físico-química de sucos de laranja comercializados nas vias públicas de Porto Alegre/RS. Ciência e Tecnologia de Alimentos 2001;21(1):94–97.

Salazar GA, Guerrero-López R, Lalaleo L, Avilés-Esquivel D, Vinueza-Burgos C, Calero-Cáceres W. Presence and diversity of *Salmonella* isolated from layer farms in central Ecuador. F1000Research 2019;8:235-246.

Salvatierra G, Pinto C, Inga E, Siuce J, Calle S. Detection of *Salmonella* sp in pork carcasses in slaughterhouses in Lima, Peru. Rev Inv Vet Perú 2015;26(4):682–688.

Sánchez-Salazar E, Gudiño ME, Sevillano G, Zurita J, Guerrero-López R, Jaramillo K, Calero-Cáceres W. Antibiotic resistance of *Salmonella* strains from layer poultry farms in central Ecuador. J Appl Microbiol 2019;128(5):1347–1354.

Sánchez MJ. (2013). *Determinación de la prevalencia de Enterobacterias del género Salmonella spp. en huevos frescos de gallina de empresas avícolas de la provincia de Tungurahua*. Universidad Central del Ecuador. Retrieved from http://www.dspace.uce.edu.ec/bitstream/25000/1157/1/T-UCE-0014-36.pdf

Sánchez XM. (2016). *Identificación molecular de Salmonella spp. en un sistema integrado de producción de pollos de engorde*. Universidad Central del Ecuador. Retrieved from http://www.dspace.uce.edu.ec/bitstream/25000/11765/1/T-UCE-0014-036-2016.pdf

Sant'Ana AS, Landgraf M, Destro MT, Franco B. Prevalence and counts of *Salmonella* spp. in minimally processed vegetables in São Paulo, Brazil. Food Microbiol 2011;28(6):1235–1237.

Santos D, Junior A, Fernandes S, Tavechio AT, Amaral LA do. *Salmonella* em carcaças de frango congeladas. Pesqui Vet Bras 2000;20(1):39–42.

Santos FF, Aquino MH, Nascimento ER, Abreu DL, Gouvêa R, Rodrigues DP, Reis EM, Araújo MS, Pereira VL. Chicken feet bacteriological quality at 4 steps of technological processing. Poult Sci 2011;90(12):2864–2868.

Santos R dos, Xavier R, Oliveira T de, Leite R, Figueiredo HC, Leal CA. Occurrence, genetic diversity, and control of *Salmonella enterica* in native Brazilian farmed fish. Aquaculture 2019;501:304–312.

Seixas F, Tochetto R, Ferraz SM. Presença de *Salmonella* sp. em carcaças suínas amostradas em diferentes pontos da linha de processamento. Ciênc Anim Bras 2009;10(2):634–640.

Silva KC, Fontes LC, Moreno AM, Astolfi-Ferreira CS, Ferreira AJ, Lincopan N. Emergence of extended-spectrum-β-lactamase CTX-M-2-producing *Salmonella* enterica serovars Schwarzengrund and agona in poultry farms. Antimicrob Agents Ch 2013;57(7):3458–3459.

Silva LE, Dias V, Ferronatto A, Guerra P, Berno L, Triches N, Kich J, Corbellini LG, Cardoso M. Longitudinal dissemination of *Salmonella enterica* clonal groups through the slaughter process of *Salmonella*-positive pig batches. J Food Prot 2012;75(9):1580–1588.

Silva LE, Gotardi CP, Vizzotto R, Kich JD, Cardoso MR. Infecção por *Salmonella enterica* em suínos criados em um sistema integrado de produção do sul do Brasil. Arq Bras Med Vet Zootec 2006;58(4):455–461.

Silva R de, Gonçalves G, Lazzari AM, Mulinari F. Prevalência de *Salmonella* spp. em suínos abatidos em um frigorífico do Distrito Federal determinada pela técnica de PCR. Braz J Food Technol 2018;21:1-6.

Solano CS. (2016). *Incidencia de los tipos de Salmonella en los huevos de gallina criolla que se expenden en los mercados de Guaranda, Chimbo y San Miguel*. Universidad Estatal de Bolívar. Retrieved from http://dspace.ueb.edu.ec/handle/123456789/1632

Soria MC, Soria MA, Bueno DJ, Godano EI, Gómez SC, ViaButron IA, Padin VM, Rogé AD. *Salmonella* spp. contamination in commercial layer hen farms using different types of samples and detection methods. Poult Sci 2017;*96*(8):2820–2830.

Soto-Varela ZE, Gutiérrez CG, Moya Y de, Mattos R, Bolívar-Anillo HJ, Villarreal JL. Detección molecular de *Salmonella* spp., *Listeria* spp. y *Brucella* spp. en queso artesanal fresco comercializado en Barranquilla: un estudio piloto. Biomedica 2018;38:30–36.

Souza IA de, Giovannetti AC, Santos LG, Gandra SO, Martins M, Ramos A. Qualidade microbiológica de queijo Minas frescal comercializado na Zona da Mata Mineira. Rev Inst Laticínios Cândido Tostes 2017;72(3):152–162.

Spricigo DA, Matsumoto SR, Espíndola ML, Ferraz SM. Prevalência, quantificação e resistência a antimicrobianos de sorovares de *Salmonella* isolados de lingüiça frescal suína. Ciencia e Tecnologia de Alimentos 2008;28(4):779–785.

Spricigo DA, Matsumoto SR, Espíndola ML, Vaz EK, Ferraz SM. Prevalência e perfil de resistência a antimicrobianos de sorovares de *Salmonella* isolados de lingüiças suínas tipo frescal em Lages, SC. Arq Bras Med Vet Zootec 2008;60(2):517–520.

Takayanagui OM, Oliveira CD, Bergamini A, Capuano DM, Okino M, Febrônio L, Castro A, Oliveira MA, Ribeiro E, Takayanagui AM.

Monitoring of vegetables comercially sold in Ribeirão Preto, SP, Brazil. Rev Soc Bras Med Trop 2001;34(1):37–41.

Takayanagui OM, Febrônio LH, Bergamini AM, Okino MH, Silva A, Santiago R, Capuano DM, Oliveira MA, Takayanagui AM. Fiscalização de hortas produtoras de verduras do município de Ribeirão Preto, SP. Rev Soc Bras Med Trop 2000;33(2):169–174.

Talavera M, Reyes NE, Lagunas S, Fernández P, Morales V, Soriano E. (2011). Variabilidad genética de aislamientos de *Salmonella typhimurium* (grupo B) obtenidos de hígados de pollo destinados para consumo humano. Rev Mex Cienc Pecu 2011;2(4):371–380.

Tejada TS, Silva CS, Lopes NA, Silva DT, Agostinetto A, Silva EF, Menezes DB, Timm CD. DNA profiles of *Salmonella* spp. isolated from chicken products and from broiler and human feces. Rev Bras Cienc Avic 2016;18(4):693–700.

Tessari E, Cardoso AL, Kanashiro AM, Stoppa GF, Luciano RL, de Castro A. Ocorrência de *Salmonella* spp. em carcaças de frangos industrialmente processadas, procedentes de explorações industriais do Estado de São Paulo, Brasil. Ciencia Rural 2008;38(9):2557–2560.

Tessmann C, Zocche F, De Lima A, Bassani M, Lopes G, Da Silva W. Ocorrência e perfil de sensibilidade a antibióticos de *Salmonella* spp. isolada em cortes de carne suína comercializados en feiras-livres de Pelotas (RS). Bol Cent Pesqui Process Aliment 2008;26(2):307–313.

Tiba-Casas MR, Camargo CH, Soares FB, Doi Y, Fernandes SA. Emergence of CMY-2-producing *Salmonella* Heidelberg associated with IncI1 plasmids isolated from poultry in Brazil. Microb Drug Resist 2019;25(2):271-276.

Tirolli IC, Da Costa C. Occurrence of *Salmonella* spp. in chicken carcasses commercialized in open markets in the city of Manaus - Amazonas. Acta Amaz 2006;36(2):205–208.

Torres-Vitela MR, Escartin EF, Castillo A. Risk of salmonellosis associated with consumption of chocolate in Mexico. J Food Prot 1995;58(5):478–481.

Torres-Vitela MD, Gómez Aldapa CA, Cerna-Cortes JF, Villarruel-López A, Rangel-Vargas E, Castro-Rosas J. Presence of indicator bacteria, diarrhoeagenic *Escherichia coli* pathotypes and *Salmonella* in fresh carrot juice from Mexican restaurants. Lett Appl Microbiol 2012;56(3):180-185.

Torres-Vitela MR, Mendoza-Bernardo M, Castro-Rosas J, Gomez-Aldapa CA, Garay-Martinez LE, Navarro-Hidalgo V, Villarruel-López A. (2012). Incidence of *Salmonella*, *Listeria monocytogenes*, *Escherichia coli* O157:H7, and staphylococcal enterotoxin in two types of

Mexican fresh cheeses. J Food Prot 2012;75(1):79–84.

Ulloa J, González M, Hernández C, Villanueva MP, Fernández H. *Salmonella* Enteritidis in chicken carcasses and giblets in Southern Chile. J Infect Dev Ctries 2010;4(2):107–109.

Valadez F, Hernández MC, García EM, Ramírez LY, Flores JF, Rodríguez GC, Acosta RI. Microbiological quality of ready-to-eat street-vended flavored waters and fruits salads in Reynosa, Tamaulipas, Mexico. Acta Univ 2017;27(6):3–9.

Varela-Guerrero JA, Talavera-Rojas M, Gutiérrez-Castillo AC, Reyes-Rodríguez NE, Vázquez-Guadarrama J. Phenotypic-genotypic resistance in *Salmonella* spp. isolated from cattle carcasses from the north central zone of the State of Mexico. Trop Anim Health Prod 2013;45(4):995–1000.

Vaz CS, Streck AF, Michael GB, Marks FS, Rodrigues DP, Reis EM dos, Cardoso MR, Canal CW. (2010). Antimicrobial resistance and subtyping of *Salmonella enterica* subspecies *enterica* serovar Enteritidis isolated from human outbreaks and poultry in southern Brazil. Poult Sci 2010;89(7):1530–1536.

Viana C, Sereno M, Pegoraro K, Yamatogi R, Call DR, Bersot L, Nero LA. Distribution, diversity, virulence genotypes and antibiotic resistance for *Salmonella* isolated from a Brazilian pork production chain. Int J Food Microbiol 2019;310:1-7.

Vieira RH, de Lima E, Sousa D, dos Reis E, Costa R, Rodrigues D. *Vibrio* spp. and *Salmonella* spp., presence and susceptibility in crabs *Ucides cordatus*. Rev Inst Med Trop Sao Paulo 2004;46(4):179–182.

Villagómez SD. (2015). *Aislamiento y serotipificación de Salmonella Enteritidis, Typhimurium, e Infantis en carcasas de pollo destinadas para consumo humano en un camal industrializado de la provincia de Pichincha*. Universidad Central del Ecuador. Retrieved from

Villalpando-Guzmán S, Vázquez-Quiñones CR, Natividad-Bonifacio I, Curiel-Quesada E, Quiñones-Ramírez EI, Vázquez-Salinas C. Frecuencia, susceptibilidad antimicrobiana y patrón de adherencia de *Salmonella enterica* aislada de carne de pollo, res y cerdo de la ciudad de México. Rev Chilena Infectol 2017;34(5):458–466.

Vinueza-Burgos C, Baquero M, Medina J, De Zutter L. Occurrence, genotypes and antimicrobial susceptibility of *Salmonella* collected from the broiler production chain within an integrated poultry company. Int J Food Microbiol 2019;299:1–7.

Volcão L, Marques J, Bernardi E, Ribeiro G. Saúde e segurança alimentar: isolamento e análise do perfil de suscetibilidade de bactérias patogênicas de alimentos. R Epidemiol Control Infec 2016;6(4):1–6.

Weiler N, Orrego M, Alvarez M, Huber C, Ortiz F, Nuñez L, Piris L, Perez J. (2017). First results of the comprehensive surveillance of the antimicrobial resistance of foodborne pathogens, *Campylobacter* spp. and *Salmonella* spp., in three different populations. Paraguay, 2011-2012. Mem Inst Investig Cienc Salud 2017;15(2):64–72.

Werlang G, Haubert L, Peter C, Cardoso M. Isolation of *Salmonella* Typhimurium, *Listeria monocytogenes* and coagulase-positive *Staphylococcus* from salami sold at street fairs in Porto Alegre, Brazil. Arq Inst Biol 2019;86:1–6.

Wiesner M, Hidalgo M, Castañeda E, Agudelo CI. Molecular analysis of *Salmonella* Enteritidis and Typhimurium clinical and food isolates by pulsed-field gel electrophoresis in Bogotá, Colombia. Microb Drug Resist 2006;12(1):68–73.

Wilson IG. (2004). Antimicrobial resistance of *Salmonella* in raw retail chickens, imported chicken portions, and human clinical specimens. J Food Prot 2004;67(6):1220–1225.

Yamaguchi M, Zanqueta É, Moarais J, El Ghoz H, Silvério KI. Qualidade microbiológica de alimentos e de ambientes de trabalho: pesquisa de *Salmonella* e *Listeria*. Rev em Agronegócio e Meio Ambient 2013;6(3):417–434.

Yamatogi RS, Oliveira HC, Camargo, CH, Fernandes SA, Hernandes RT, Pinto JP, Rall VL, Júnior JP. Clonal relatedness and resistance patterns of *Salmonella* corvallis from poultry carcasses in a Brazilian slaughterhouse. J Infect Dev Ctries 20200815;9(10):1161–1165.

Zaidi MB, Calva JJ, Estrada-Garcia MT, Leon V, Vazquez G, Figueroa G, Lopez E, Contreras J, Abbott J, Zhao S, McDermott P, Tollefson L. Integrated food chain surveillance system for *Salmonella* spp. in Mexico. Emerg Infect Dis 2008;14(3):429–435.

Zaidi MB, Campos FD, Estrada-García T, Gutierrez F, León M, Chim R, Calva JJ. Burden and transmission of zoonotic foodborne disease in a rural community in Mexico. Clin Infect Dis 2012;55(1):51–60.

Zaidi MB, McDermott PF, Fedorka-Cray P, Leon V, Canche C, Hubert SK, Abbot J, León M, Zhao S, Headrick M, Tollefson L. Nontyphoidal *Salmonella* from human clinical cases, asymptomatic children, and raw retail meats in Yucatan, Mexico. Clin Infect Dis 2006;42(1):21–28.

CHAPTER 2

Microbial Biotechnology. First published: 19 July 2020.
https://doi.org/10.1111/1751-7915.13624

Salmonella grows massively and aerobically in chicken faecal matter

Teresa Guerrero[1]*, Diana Calderón[1], Sonia Zapata[1] and Gabriel Trueba[1]

[1] Microbiology Institute, Universidad San Francisco de Quito.

* Corresponding author: Teresa Guerrero. Universidad San Francisco de Quito, Diego de Robles y Vía Interoceánica, Cumbayá, Quito, Ecuador. Tel. (593) 2 2971700; Fax (593) 2 2890070. E-mail: tguerrero@estud.usfq.edu.ec

Summary

The use of wastewater for irrigation and animal manure as fertilizer can cause transmission of intestinal pathogens, conditions frequently observed in Low- and Middle-Income Countries (LMICs). Here we tested the ability of *Salmonella* to grow in the faecal matter. We inoculated freshly isolated *Salmonella* strains (from chickens) in chicken faecal matter and incubated for 1 to 12 days, under aerobic and anaerobic conditions. We found that both *Salmonella* and *Escherichia coli* multiplied massively in faecal matter outside a host and significantly higher in aerobic conditions. Our results have critical implications in waste management, as we demonstrate that aerobic treatments may not be the best to reduce the number of *Salmonella* in the environment.

Introduction

Environmental transmission of intestinal pathogens is extremely important especially in Low- and Middle-Income Countries (LMICs) due to deficient sanitary infrastructure, unplanned

urban growth, lack of wastewater treatment, etc. One of the main concerns in LMICs is the large proportion of untreated wastewater used for irrigation (Khalid *et al*., 2018) and the increasing use of animal manure as fertilizer without suitable treatment (Mandrell, 2009). Reports of grave enteric infections caused by environmental contamination of edible vegetables are also commonplace nowadays in industrialized countries (Callejón *et al*., 2015). Some of these outbreaks have been associated with high mortality, morbidity, and large economic losses. The incidence of these infections is exacerbated by the increasing appeal to consume natural, non-processed fresh products (Mandrell, 2009).

Salmonella-contaminated water is responsible for a large number of outbreaks by the ingestion of water or produce (Mandrell, 2009); the sources for this contamination are human and non-human faecal matter (Medrano-Félix *et al.*, 2017). The use of animal waste as fertilizer constitutes a serious risk that can be controlled by appropriate composting technology (Tiquia *et al.*, 1998; Szogi *et al.*, 2015;). Human waste contamination, however, is much more difficult to monitor or control in LMICs where wastewater treatment or toilets are not available (Khalid *et al.*, 2018). The fate of *Salmonella* in these conditions is not understood completely, although some researchers indicate that *Salmonella* enters into a viable-non culturable state outside the host (Winfield and Groisman, 2003). The reduction of the risk of this type of transmission requires an understanding of every aspect of *Salmonella* physiology in the environment outside the host (Mandrell, 2009). It is worth mentioning that *Salmonella*'s ability to grow in the faecal matter has been ignored.

It is known that *Salmonella* and other *Enterobacteriaceae* survive in faecal matter for some time and it has been shown that *Escherichia coli* (another member of the *Enterobacteriaceae*) also grows massively in faecal matter (Russell and Jarvis, 2001; Vasco *et al.*, 2015; Sharma *et al.*, 2019). Here we tested *Salmonella*'s ability to grow in faecal matter in aerobic and anaerobic conditions and discuss the potential implications for faecal waste management.

Results and discussion

Two trials were performed with *Salmonella* Infantis inoculated in chicken faecal matter. In the first trial we determined the growth of *Salmonella* by plate counting and by molecular detection after 0, 24, 48 and 72 h of incubation; in the second trial, we performed *Salmonella* plate counting daily, from day 0 to day 12 of incubation (Fig. 1).

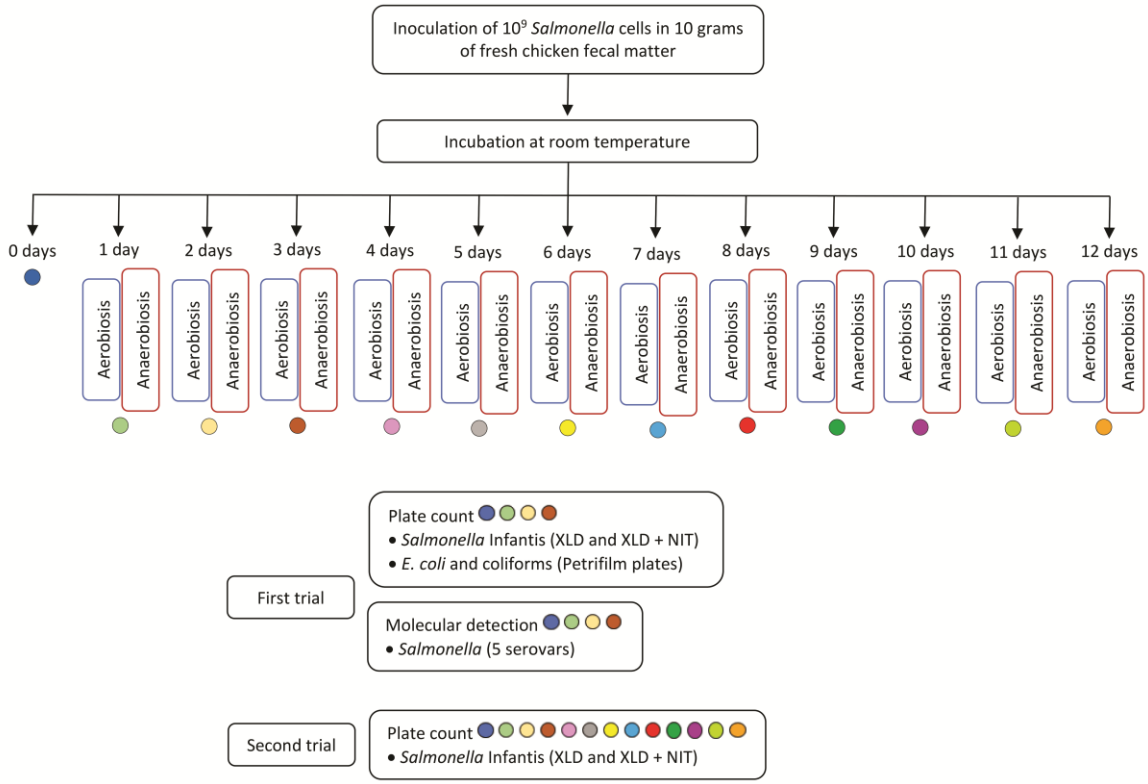


Fig. 1. Scheme of experimental procedures. The experiments performed in trial 1 and in trial 2 are indicated. In the first trial, we determined the growth of *Salmonella* by plate counting in XLD and XLD with nitrofurantoin (NIT), and by molecular detection after 0, 24, 48 and 72 h of incubation; in the second trial, we performed *Salmonella* plate counting daily, from day 0 to day 12 of incubation.

In the first trial, *Salmonella* Infantis inoculated in chicken faecal matter multiplied in both aerobic and anaerobic conditions; however, the aerobic growth was significantly higher than the anaerobic growth at 48 h ($P = 1.28 \times 10^{-4}$) and 72 h ($P = 2.94 \times 10^{-4}$). Similarly, endogenous *E. coli* growth reached its peak after 48 h, predominantly in aerobiosis ($P = 1.92 \times 10^{-2}$) and

from then on, its growth rate decreased (Fig. 2, Figs. S1-S4). The growth curve of total endogenous coliforms was similar to that of *E. coli*, with a peak in aerobiosis at 48 h (P = 1.30 x 10^{-2}), but their counts were higher (Fig. S5).

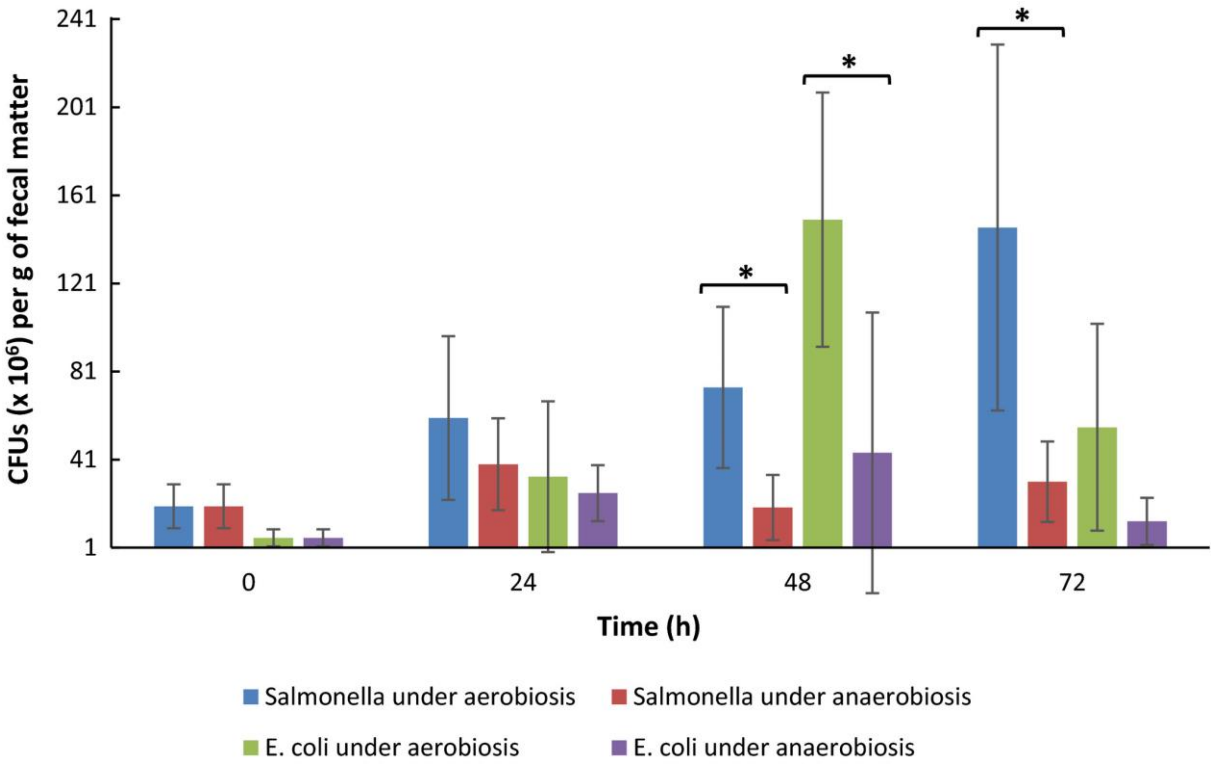


Fig. 2. Growth of *Salmonella* Infantis and endogenous *E. coli* in chicken faecal matter, under aerobic and anaerobic conditions. Typical *Salmonella* colonies were counted in XLD and XLD with NIT (12 mg L−1) (we took advantage of the *Salmonella* strain's resistance to nitrofurantoin to facilitate *Salmonella* colony count), and *E. coli* was counted in 3M™ Petrifilm E. coli/Coliform Count Plates. Data shown are means ± SD. Asterisks indicate a statistically significant difference (t-test, P < 0.05) between aerobic and anaerobic growth. The number of Petri dishes counted (replicate counts) is represented by *n*. For *Salmonella* 0 h, 72 h of aerobiosis and 48 h of anaerobiosis *n* = 14; for 24 h of aerobiosis *n* = 15; for 48 h of aerobiosis *n* = 6; for 24 h of anaerobiosis *n* = 16; and for 72 h of anaerobiosis *n* = 10. For *E. coli* 0 h, 24 h of anaerobiosis and 72 h of anaerobiosis *n* = 6; for 24 h of aerobiosis *n* = 7, for 48 and 72 h of aerobiosis *n* = 4; and for 48 h of anaerobiosis *n* = 8. These experiments were performed twice and corresponded to the first trial.

Escherichia coli had the highest specific growth rate (μ) during the second day in aerobiosis (P = 8.14 x 10^{-8}), decreasing in the following 24 h; *Salmonella* started fast growth at 24 h and presented significantly higher values of μ in aerobiosis than in anaerobiosis at all time intervals (for Δt1, Δt2, and Δt3, P = 7.49 x 10^{-5}, 6.93 x 10^{-7} and 9.73 x 10^{-3}, respectively). Likewise,

endogenous coliforms presented higher μ values in aerobiosis than in anaerobiosis after 48 hours (P = 1.83 x 10^{-2}) (Fig. 3).

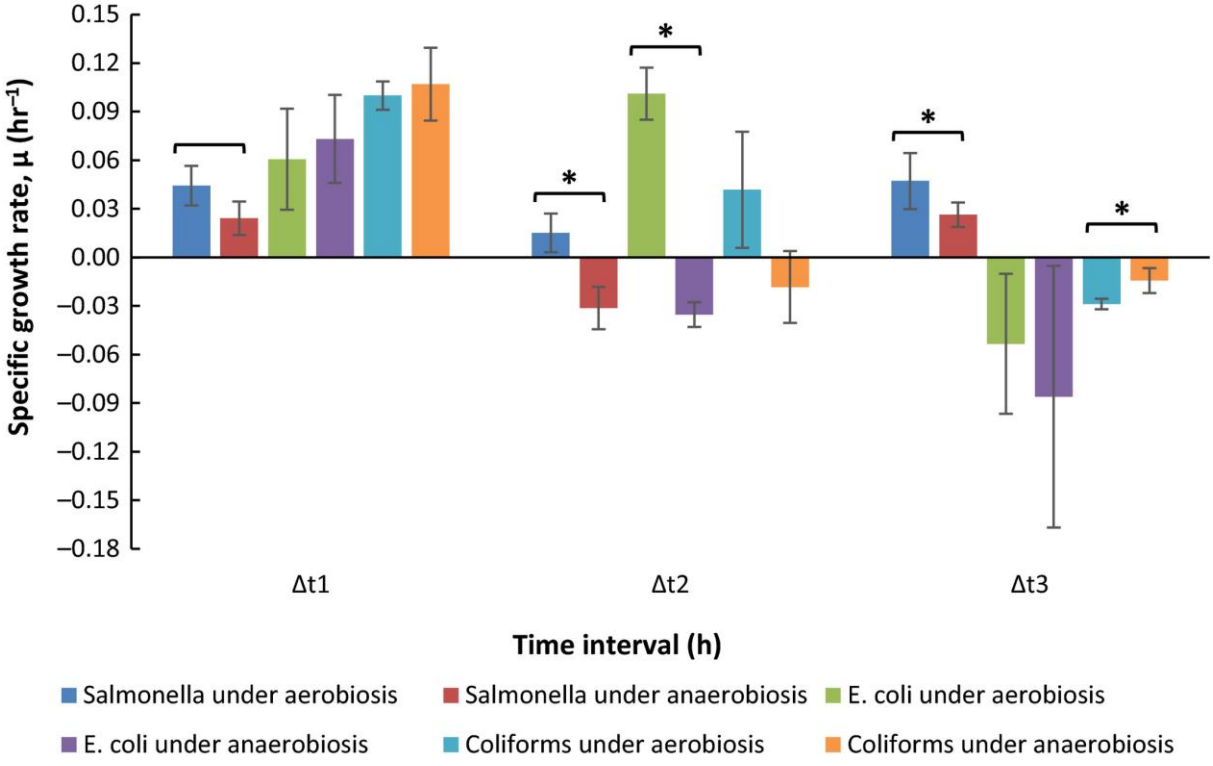


Fig. 3. Specific growth rate for *Salmonella* Infantis, endogenous *E. coli* and total coliforms, under aerobic and anaerobic conditions. Specific growth rate, μ, was calculated with the formula: $\mu = \frac{2.3 \log(\frac{N}{No})}{\Delta t}$, where N is the final population after a time interval of incubation, Δt, and No is the initial population. The incubation times were: t1 = 0 h, t2 = 24 h, t3 = 48 h and t4 = 72 h. And the intervals were: Δt1 = t2 - t1, Δt2 = t3 - t2, and Δt3 = t4 - t3. Data shown are means ± SD. Asterisks indicate a statistically significant difference (*t*-test, $P < 0.05$) between aerobic and anaerobic conditions. The number of Petri dishes counted is represented by *n*. For *Salmonella* Δt1 aerobiosis and anaerobiosis, and Δt2 anaerobiosis *n* = 14; for Δt2 and Δt3 aerobiosis *n* = 6; for Δt3 anaerobiosis *n* = 8. For *E. coli* Δt1 aerobiosis and anaerobiosis, Δt2 anaerobiosis and Δt3 anaerobiosis *n* = 6; for Δt2 and Δt3 aerobiosis *n* = 4. For total coliforms Δt1, Δt2 and Δt3 aerobiosis, and for Δt1 anaerobiosis *n* = 4; for Δt2 and Δt3 anaerobiosis *n* = 3. These data correspond to the first trial.

To determine whether the above growth pattern could be applied to other *Salmonella* serovars, in the first trial we run isothermal amplification 3M™ Molecular Detection Assay 2 - *Salmonella* (MDA2SAL) at different incubation times (under aerobiosis and anaerobiosis) with 5 *Salmonella* strains (belonging to different serovars) inoculated in chicken faecal matter. The molecular assay was performed daily until day 3 after incubation (0 to 72 h). For serovars

Infantis, Heidelberg, Brandenburg, and Stanley the growth peak in aerobiosis was observed at 72 h (P = 1.19 x 10^{-3}), while serovar Dublin growth peak occurred at 48 hours (Fig. 4, Fig. S6).

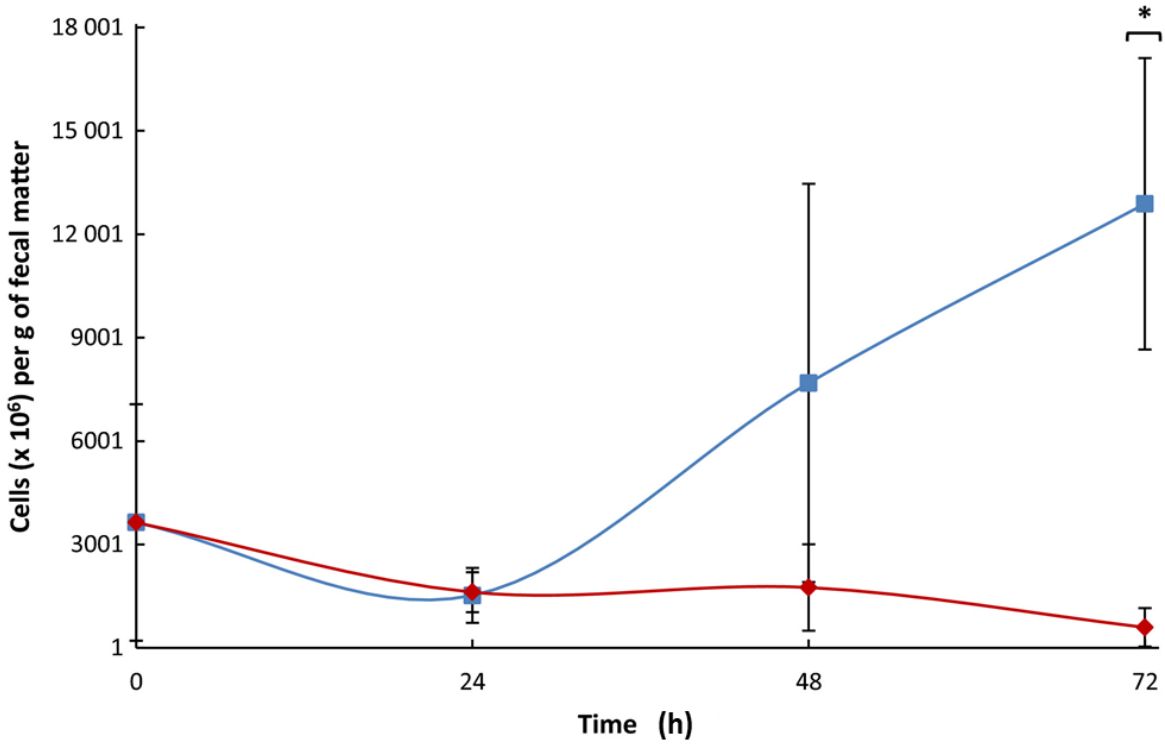


Fig. 4. Growth curves of *Salmonella* serovars: Infantis, Heidelberg, Brandenburg, and Stanley. Curves were obtained by 3M™ Molecular Detection Assay 2 - *Salmonella* (MDA2SAL). The blue line corresponds to the growth under aerobic conditions and the red one, to the growth under anaerobic conditions. Data shown are means ± SD. Asterisk indicates a statistically significant difference (*t*-test, $P < 0.05$) between aerobic and anaerobic growth. The number of independent readings is represented by *n*; for all data points $n = 4$. The experiment was performed once and corresponded to the first trial.

In a subsequent experiment (trial 2), no colonies of *Salmonella* in XLD or XLD with NIT were observed in aerobiosis between days 2 and 6 of incubation, probably because of a massive growth of lactose-fermenting bacteria (yellow colonies) corresponding to the commensal *Enterobacteriaceae*. Increasing *Salmonella* counts were detected on day 7 and reached a peak on day 9 (1.8 x 10^8 cells per g of faecal matter) (Fig. S7), which coincided with a reduction in the number of lactose fermenting bacteria colonies. On days 10 to 12, *Salmonella* growth was not detected, but lactose fermenters kept on growing, and glucuronidase reaction indicated that 94% of them were *E. coli*. We suspect that the massive growth of lactose-fermenting bacteria

was due to a different diet used in chickens during the second trial (Shang *et al*., 2018). In anaerobiosis, we observed no growth of *Salmonella* or lactose fermenting bacteria from day 1 to 12.

Growth rates of *Salmonella* and *E. coli,* at different incubation time intervals, suggested a negative correlation which may indicate antagonism between these two bacterial genera (Fig. 3). We posit that *E. coli*'s initial massive replication may limit the availability of oxygen for *Salmonella* growth; once *E. coli* growth begins to decrease, *Salmonella* grows faster. Competition between these two bacterial genera has been described previously in the gut (Barrow *et al.*, 2015; Velazquez *et al.*, 2019) and in ready-to-eat and fresh foods, to such an extent that some authors consider that *E. coli* may not be a good indicator of *Salmonella* (Gómez-Aldapa *et al*., 2013).

To investigate whether there was antagonism between *Salmonella* and *E. coli* in faeces, we inoculated equal concentrations (10^9 cells) of *S.* Infantis and an *E. coli* (isolated from chicken) in 10 g of sterile chicken faecal matter; inoculated samples were incubated in aerobiosis and anaerobiosis for 6 days. We observed that aerobic *E. coli* growth from day 3th to 6th was significantly higher than *Salmonella*'s (*P* values days 3 to 6 were: 1.20×10^{-5}, 1.86×10^{-2}, 1.54×10^{-6} and 5.09×10^{-5}, respectively) (Fig. S8), which suggests some level of competition between these two bacteria. This finding is in agreement with previous reports (Shang *et al.*, 2018). There were two differences between the results of the experiments in fresh faecal matter and sterilized faecal matter: (i) the interference of *E. coli* growth occurred later in sterile faecal matter (Fig. 2, Fig. S8); and (ii) there was no difference between growth under aerobic or anaerobic conditions, except for *Salmonella* on day 5 (Fig. S9). These differences may be due to physical and chemical modifications of the faecal matter by heat sterilization; autoclaved faecal matter was drier and harder probably due to dehydration and starch gelatinization

(Weurding *et al.*, 2001). Additionally, lower water activity may protect *Salmonella* (Santos *et al.*, 2005).

To ascertain whether the aerobic or anaerobic environments are determining factors in the growth of *Salmonella* and *E. coli* in chicken faecal matter we inoculated fresh faecal matter with *Lactobacillus reuteri* strain *LrRR* (López *et al.*, 2019), an anaerobic bacterium (Kandler *et al.*, 1980; Ianniello *et al.*, 2015), and our results showed that the growth of LrRR was significantly higher in anaerobiosis on days 2 and 3 (P = 4.48 x 10^{-3} and 6.86 x 10^{-5}, respectively) (Fig. S10), which is an additional evidence that the presence or absence of oxygen in the environment is a factor that determines the differential growth of *Salmonella* and *E. coli* in fresh chicken faeces. On day 6, we observed that LrRR growth in aerobiosis and anaerobiosis produced the same numbers of colonies; we speculate that aerotolerant mutant bacteria may have been selected during the incubation period, a phenomenon described previously in *Lactobacillus* (Ianniello *et al.*, 2015).

Our results indicate that *Salmonella* and other *Enterobacteriaceae* multiply massively and aerobically in fresh chicken faecal matter; in fact, faecal matter incubated under aerobic conditions has more *Salmonella* (on average 10 times more) than freshly released faeces. Our results show clear evidence that the faecal matter is a transient but very important component of the *Enterobacteriaceae* life cycle, where enterobacterial population expands (Russell and Jarvis, 2001; Vasco *et al.*, 2015; Barrera *et al.*, 2018) increasing the chances of reaching other hosts.

Previous studies have shown that *E. coli* has a negative growth rate outside the host, with a short half-life (1 day in water, 1.5 days in sediment and 3 days in soil) (Winfield and Groisman, 2003); however, we have found that as long as it remains in faecal matter, *E. coli* continues to grow up to 12 days after being excreted in the environment (intermediate habitat) (Barrera *et al.*, 2018). Also, it has been estimated that the doubling time of *E. coli* in its primary habitat

(the intestine of warm-blooded animals) is 2 days (Winfield and Groisman, 2003), and our results indicate that its doubling time in the intermediate habitat during the first two days is less than 24 hours (Fig. 2, Fig. S1). Our findings disagree with the notion that these bacteria enter a viable but not culturable status when excreted from the host (Winfield and Groisman, 2003). Additional studies are needed due to the relevance of this issue in public health.

Microbiologists have struggled to explain why bacteria adapted to the anaerobic intestinal milieu possess energetically costly machinery to use oxygen (Govantes *et al.*, 2000). Further, it has been shown that aerobic respiration is not important for *Salmonella* intestinal colonization (Barrow *et al.*, 2015). We hypothesize that the reason for this apparent evolutionary mystery may be related to the enterobacterial ability to grow in faecal matter under aerobic conditions. *Enterobacteriaceae* are facultative anaerobe which can synthesize ATP by different enzymatic pathways, depending on the external concentration of O_2 and the redox changes in the environment. When O_2 is available, the bacteria obtain energy by aerobic respiration, with O_2 being the final acceptor of electrons. In shortage of O_2, these bacteria generate ATP by one of the following mechanisms: (i) synthesis of terminal oxidases that allow the bacteria to take advantage of traces of O_2; (ii) use of other inorganic molecules (such as NO_3^- and $S_4O_6^{2-}$) as final electron acceptors (Yamamoto and Droffner, 1985; Bueno *et al.*, 2012; Rivera *et al.*, 2013); and (iii) use of organic compounds as donors and acceptors (Madigan *et al.*, 2012). However, aerobic respiration produces much better performance in terms of ATP molecules per substrate molecule (Madigan *et al.*, 2012).

Salmonella is responsible for hospitalizations and deaths worldwide (Omer *et al*., 2018; EFSA and ECDC, 2019) due to outbreaks associated not only with animal products but also with vegetables (Gunel *et al*., 2015; Omer *et al*., 2018). The presence of *Salmonella* in produce is associated with unintended environmental faecal contamination and the use of untreated manure as fertilizer (Fletcher *et al.*, 2013). Our results have critical implications in waste

management, contribute to select more efficient ways of treating manure through composting (Singh *et al*., 2012; Román *et al*., 2015) and suggest the need of anaerobic treatments for animal waste.

The loose consistency of avian faeces allows the entry of air and this phenomenon may contribute to the proficiency of these animals to spread *Salmonella*. Similarly, loose stools caused by *Salmonella* infection, may favor the growth of this bacterium in faecal matter from animals with different faecal texture.

The inconsistencies found in this study are probably due to the complex composition of faecal matter (food substrates and microbiota). Another limitation was the abundant growth of accompanying bacteria (lactose fermenters) that made it difficult the detection of *Salmonella* in XLD.

This type of studies is important because it helps to understand better the physiology of *Salmonella* and other members of the *Enterobacteriaceae* family. We addressed a neglected but crucial characteristic of *Salmonella* life cycle which may have an impact in public health.

Acknowledgments

We want to thank Alejandro Torres for providing us with *Salmonella*-free chickens for carrying out these experiments. We thank Karen Pacheco and Brenda Tito for their help in the laboratory work. And, in a special way, we thank Dr. Harald Brussow, Editor-in-Chief of *Microbial Biotechnology*, for his valuable suggestions. This work was funded by the Universidad San Francisco de Quito USFQ Postgraduate Funds.

Conflict of interest

The authors declare no conflict of interest.

References

Barrera, S., Cardenas, P., Graham, J.P., and Trueba, G. (2018). Changes in dominant *Escherichia coli* and antimicrobial resistance after 24 hr in faecal matter. *MicrobiologyOpen* **8**: e00643.

Barrow, P.A., Berchieri, A., de Freitas Neto, O.C., and Lovell, M. (2015). The contribution of aerobic and anaerobic respiration to intestinal colonization and virulence for *Salmonella typhimurium* in the chicken. *Avian Pathol* **44**: 401–407.

Bueno, E., Mesa, S., Bedmar, E., Richardson, D.J., and Delgado, M.J. (2012). Bacterial adaptation of respiration from oxic to microoxic conditions: redox Control. *Antioxid Redox Signal* **16**: 4051.

Callejón, R.M., Rodríguez-Naranjo, M.I., Ubeda, C., Hornedo-Ortega, R., Garcia-Parrilla, M.C., and Troncoso, A.M. (2015). Reported foodborne outbreaks due to fresh produce in the United States and European Union: trends and causes. *Foodborne Pathog Dis* **12:** 32–38.

EFSA and ECDC (European Food Safety Authority and European Centre, & Control). (2019). The European Union One Health 2018 Zoonoses Report. *EFSA Journal*, **17:** 5926.

Fletcher, J., Leach, J.E., Eversole, K., and Tauxe, R. (2013). Human pathogens on plants: designing a multidisciplinary strategy for research. *Phytopathology Perspectives* **103:** 306–315.

Gómez-Aldapa, C., Rangel-Vargas, E., and Castro-Rosas, J. (2013). Frequency and correlation of some enteric indicator bacteria and *Salmonella* in ready-to-eat raw vegetable salads from Mexican restaurants. *J Food Sci* **78**: 1201–1207.

Govantes, F., Albrecht, J.A., and Gunsalus, R.P. (2000). Oxygen regulation of the *Escherichia coli* cytochrome d oxidase (cydAB) operon: roles of multiple promoters and the Fnr-1 and Fnr-2 binding sites. *Mol Microbiol* **37**: 1456–1469.

Gunel, E., Polat Kilic, G., Bulut, E., Durul, B., Acar, S., Alpas, H., and Soyer, Y. (2015). *Salmonella* surveillance on fresh produce in retail in Turkey. *Int J Food Microbiol* **199**: 72–77.

Ianniello, R.G., Zheng, J., Zotta, T., and Ricciardi, A. (2015). Biochemical analysis of respiratory metabolism in the heterofermentative *Lactobacillus spicheri* and *Lactobacillus reuteri. J Appl Microbiol* **119**: 763–775.

Kandler, O., Stetter, K., and Kohl, R. (1980). *Lactobacillus reuteri*. *Zbl Bakt Hyg I Abt Orig* **269**: 264–269.

Khalid, S., Shahid, M., Natasha, Bibi, I., Sarwar, T., Haidair, A., and Niazi, N. (2018). A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries. *Int J Environ Res Public Health* **15**: 895.

López, L., Calderón, D., Cardenas, P., Prado, M.B., Valle, C., and Trueba, G. (2019).

Evolutionary changes of an intestinal *Lactobacillus reuteri* during probiotic manufacture. *MicrobiologyOpen* **9:** e972

Madigan, M., Martinko, J., Stahl, D., and Clark, D. (2012). Chapter 4. Nutrition, Culture, and Metabolism of Microorganisms. In *Brock. Biology of Microorganisms*, 13th edn. Espinoza, D., Cook, K., Cutt, S., Hutchinson, E., Marcus, E., and Cogan, D. (eds). San Francisco, CA: Pearson Education, pp. 98-107.

Mandrell, R.E. (2009). Enteric human pathogens associated with fresh produce: sources, transport, and ecology. In *Microbial Safety of Fresh Products.* Fan, X., Niemira, B.A., Doona, C.J., Feeherry, F.E., and Gravani, R.B. (eds). Ames, IA: Blackwell Publishing and the Institute of Food Technologists, pp. 5-41.

Medrano-Félix, J.A., Castro-del Campo, N., de Peraza Garay, F.J., Martínez-Rodríguez, C.I., and Chaidez, C. (2017). Carbon source utilization-based metabolic activity of *Salmonella* Oranienburg and *Salmonella* Saintpaul in river water. *Water and Environment Journal* **32:** 118-124.

Omer, M., Álvarez-Ordoñez, A., Prieto, M., Skjerve, E., Asehun, T., and Alvseike, A. (2018). A systematic review of bacterial foodborne outbreaks related to red meat and meat products. *Foodborne Pathog Disease*, **15:** 598-611.

Rivera, F., Winter, S.E., Lopez, C.A., Xavier, M.N., Winter, M.G., Nuccio, S., *et al*. (2013). *Salmonella* uses energy taxis to benefit from intestinal inflammation. *PLOS Pathogens*, **9:** 1–13.

Román, P., Martínez, M.M., and Pantoja, A. (2015). Chapter 3. Theoretical foundations of composting. In *Farmer's Compost Handbook. Experiences in Latin America*. Santiago, Chile: Food and Agriculture Organization of the United Nations Regional Office for Latin America and the Caribbean, pp. 11–21. http://www.fao.org/3/a-i3388e.pdf.

Russell, J.B., and Jarvis, G.N. (2001). Practical mechanisms for interrupting the oral-fecal life cycle of *Escherichia coli*. *J Mol Microbiol Biotechnol* **3:** 265–272.

Santos, F.B.O., Li, X., Payne, J.B., and Sheldon, B.W. (2005). Estimation of most probable number *Salmonella* populations on commercial North Carolina Turkey Farms. *J Appl Poult Res* **14:** 700–708.

Shang, Y., Kumar, S., Oakley, B., and Kim, W.K. (2018). Chicken gut microbiota: importance and detection technology. *Front Vet Sci* **5:** 254.

Sharma, M., Millner, P.D., Hashem, F., Vinyard, B.T., East, C.L., Handy, E.T., *et al*. (2019). Survival of *Escherichia coli* in manure-amended soils is affected by spatiotemporal, agricultural, and weather factors in the Mid-Atlantic United States. *Appl Environ Microbiol*, **85:** 1–23.

Singh, R., Kim, J., and Jiang, X. (2012). Heat inactivation of *Salmonella* spp . in fresh poultry compost by simulating early phase of composting process. *J Appl Microbiol* **112:** 927–935.

Szogi, A.A., Vanotti, M.B., and Ro, K.S. (2015). Methods for treatment of animal manures to

reduce nutrient pollution prior to soil application. *Curr Pollut Rep* **1:** 47–56.

Tiquia, S.M., Tam, N.F.Y., and Hodgkiss, I.J. (1998). *Salmonella* elimination during composting of spent pig litter. *Biores Technol* **63:** 193–196.

Vasco, G., Spindel, T., Carrera, S., Grigg, A., and Trueba, G. (2015). The role of aerobic respiration in the life cycle of *Escherichia coli*: public health implications. *Avances Cienc Ingenier* **7:** B7–B9.

Velazquez, E.M., Nguyen, H., Heasley, K.T., Saechao, C.H., Gil, L.M., Rogers, A.W.L., et al. (2019). Endogenous *Enterobacteriaceae* underlie variation in susceptibility to *Salmonella* infection. *Nature Microbiology* **4:** 1057–1064.

Weurding, R.E., Veldman, A., Veen, W.A.G., Van Der Aar, P.J., and Verstegen, M.W.A. (2001). Starch digestion rate in the small intestine of broiler chickens differs among feedstuffs 1. *J Nutr* **131:** 2329–2335.

Winfield, M.D., and Groisman, E.A. (2003). Role of nonhost environments in the lifestyles of *Salmonella* and *Escherichia coli*. *Appl Environ Microbiol* **69:** 3687–3694.

Yamamoto, N., and Droffner, M.L. (1985). Mechanisms determining aerobic or anaerobic growth in the facultative anaerobe *Salmonella typhimurium*. *Proc Natl Acad Sci USA* **82:** 2077–2081.

Supplementary Material (Chapter 2)

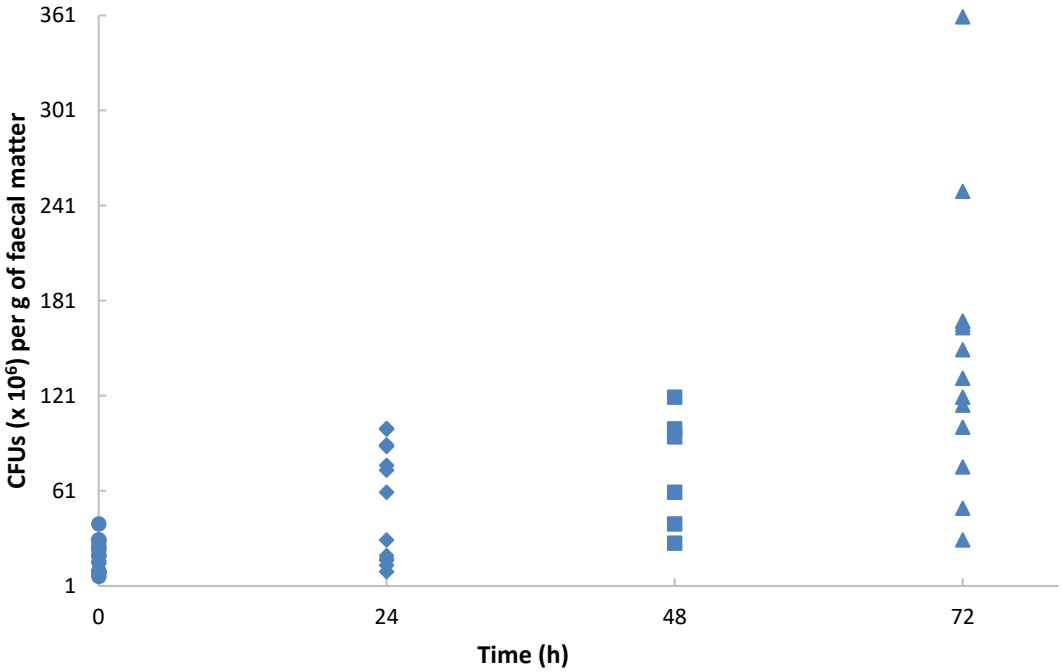


Fig. S1. Data points of the growth of *Salmonella* Infantis inoculated in chicken faecal matter, under aerobic conditions. Typical *Salmonella* colonies were counted in XLD and XLD with NIT (12 mg/L). The number of Petri dishes counted is represented by *n*; for 0 and 72 h *n* = 14, for 24 h *n* = 15, and for 48 h *n* = 6. The experiment was performed twice and corresponded to the first trial.

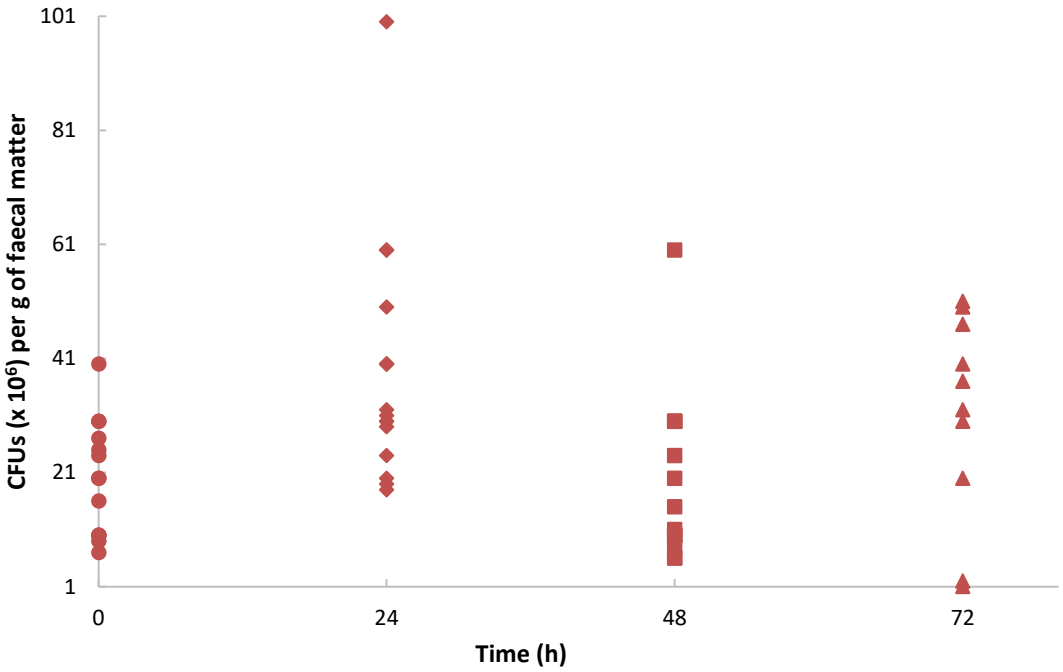


Fig. S2. Data points of the growth of *Salmonella* Infantis inoculated in chicken faecal matter, under anaerobic conditions. Typical *Salmonella* colonies were counted in XLD and XLD with NIT (12 mg/L). The number of Petri dishes counted is represented by *n*; for 0 and 48 h *n* = 14, for 24 h *n* = 16, and for 72 h *n* = 10. The experiment was performed twice and corresponded to the first trial.

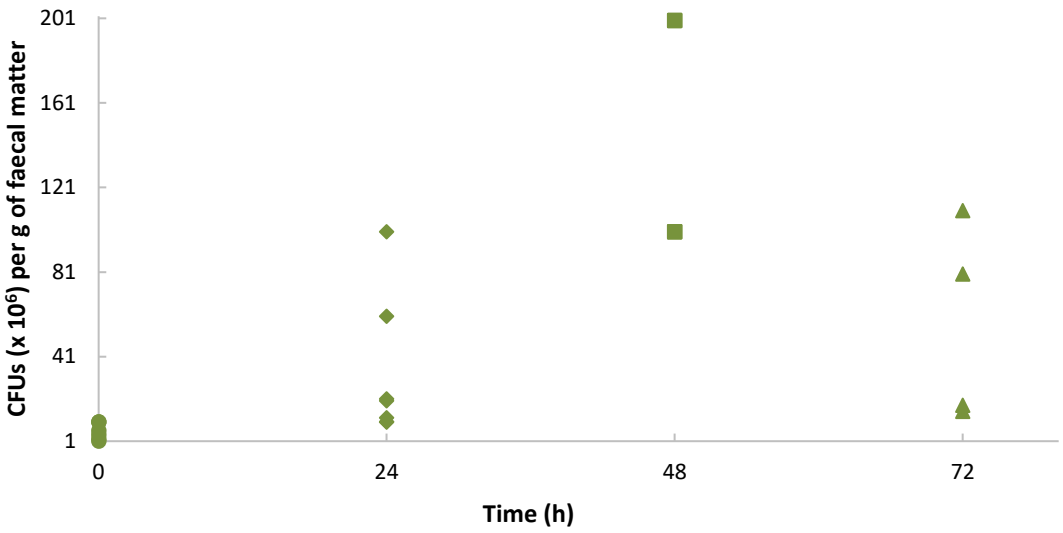


Fig. S3. Data points of the growth of endogenous *E. coli* in chicken faecal matter, under aerobic conditions. *E. coli* was counted in 3M™ Petrifilm E. coli/Coliform Count Plates. The number of Petri dishes counted is represented by *n*; for 0 h *n* = 6, for 24 h *n* = 7, for 48 and 72 h *n* = 4. The experiment was performed twice and corresponded to the first trial.

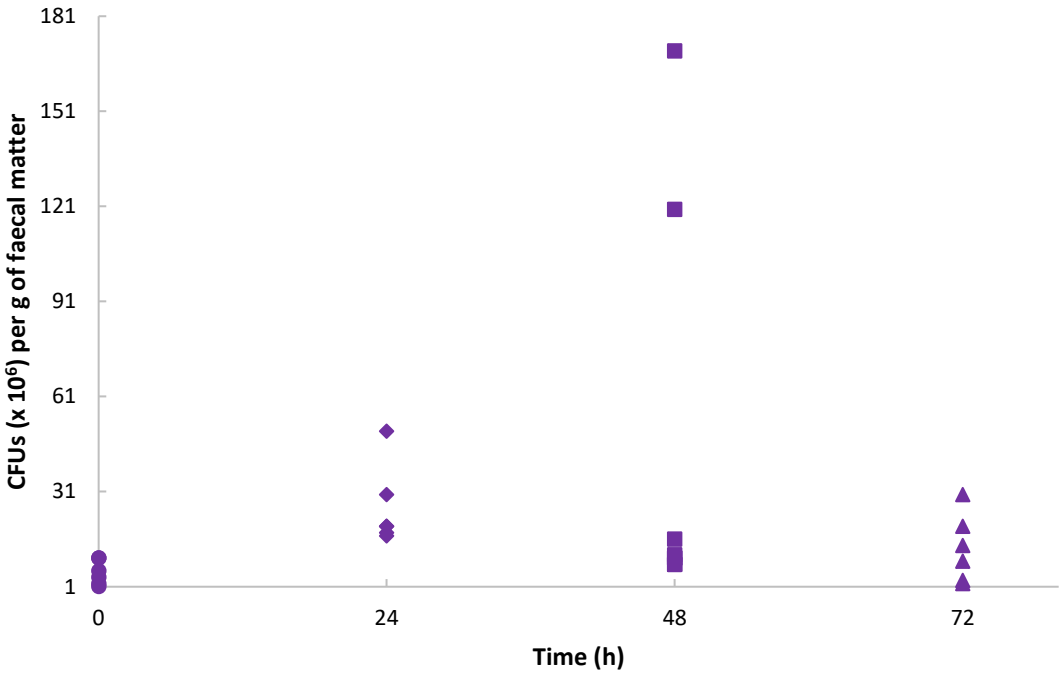


Fig. S4. Data points of the growth of endogenous *E. coli* in chicken faecal matter, under anaerobic conditions. *E. coli* was counted in 3M™ Petrifilm E. coli/Coliform Count Plates. The number of Petri dishes counted is represented by *n*; for 0, 24 and 72 h *n* = 6, for 48 h *n* = 8. The experiment was performed twice and corresponded to the first trial.

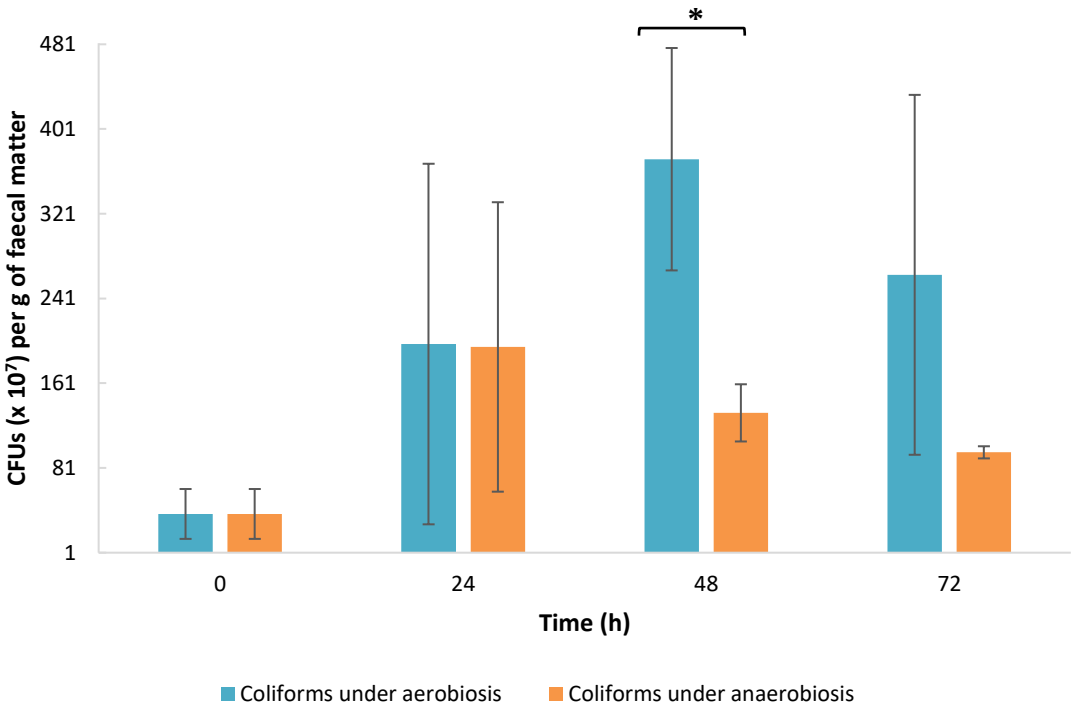


Fig. S5. Growth of endogenous total coliforms in chicken faecal matter, under aerobic and anaerobic conditions. The number of total coliforms corresponded to the sum of the red and blue colonies with gas in 3M™ Petrifilm E. coli/Coliform Count Plates incubated 24 and 48 h. Data shown are means ± SD. Asterisk indicates statistically significant difference (*t*-test, $P < 0.05$) between aerobic and anaerobic growth. The number of Petri dishes counted is represented by *n*; for 0 h $n = 8$; for 24 h aerobiosis and anaerobiosis, 48 h aerobiosis and 72 h anaerobiosis $n = 4$; for 72 h aerobiosis $n = 6$; and for 48 h anaerobiosis $n = 3$. The experiment was performed twice and corresponded to the first trial.

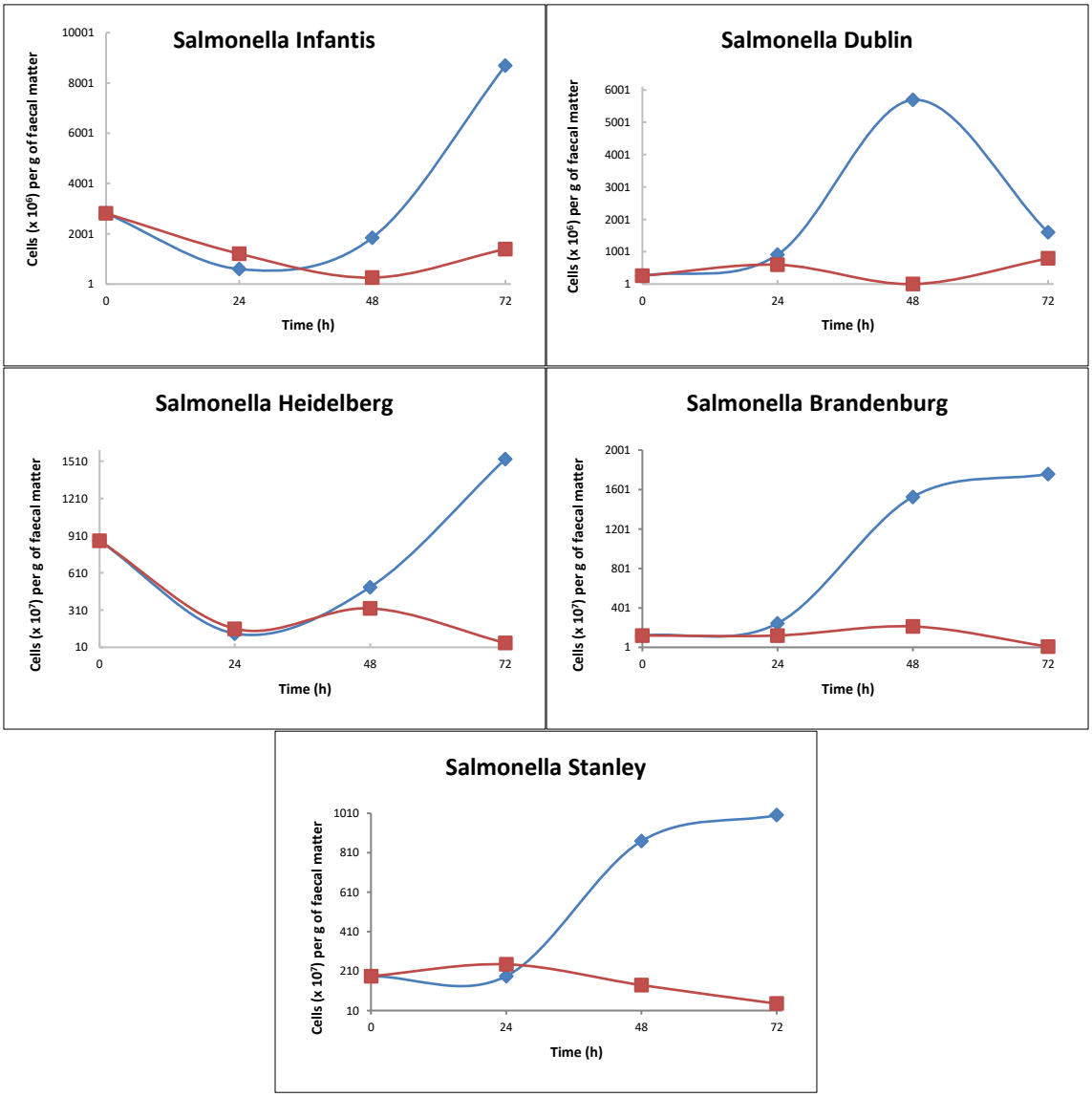


Fig. S6. Individual growth curves of *Salmonella* serovars. These curves were obtained by 3M™ Molecular Detection Assay 2 - *Salmonella* (MDA2SAL). The blue lines correspond to the growth under aerobic conditions and red ones, under anaerobic conditions. The number of independent readings is represented by *n*; for all data points *n* = 1. The experiment was performed once and corresponded to the first trial.

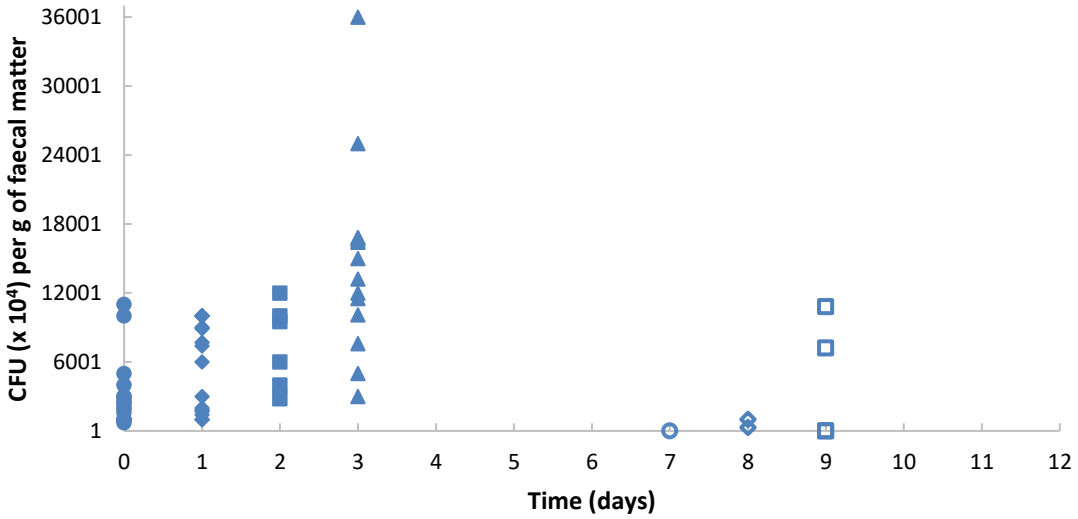


Fig. S7. Data points of the growth of *Salmonella* Infantis inoculated in chicken faecal matter, under aerobic conditions, days 0 to 12. Typical *Salmonella* colonies were counted in XLD and XLD with NIT (12 mg/L). This graph considers the results of the first trial (2 repetitions) and the second trial (1 repetition). The number of Petri dishes counted is represented by *n*. For 0 days *n* = 17, for 1 day *n* = 16, for 2 and 9 days *n* = 6, for 3 days *n* = 14, for 7 days *n* = 1 and for 8 days *n* = 2.

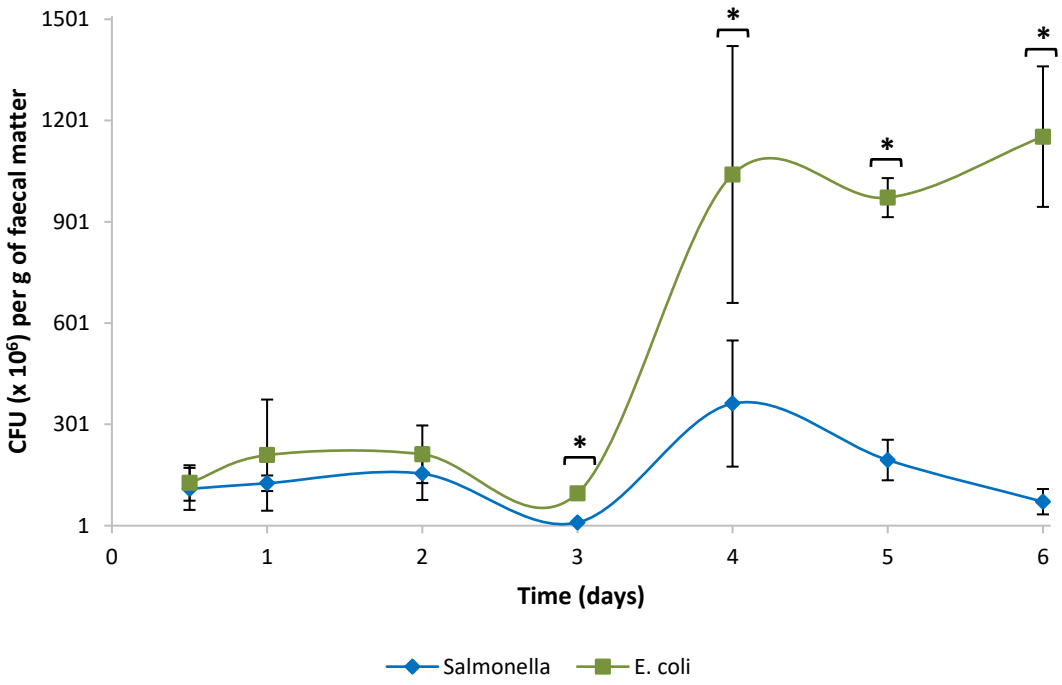


Fig. S8. Growth curves of *Salmonella* Infantis and *E. coli* inoculated in sterile faecal matter, under aerobic conditions. Colonies were counted in MKL. Data shown are means ± SD. Asterisks indicate statistically significant difference (*t*-test, $P < 0.05$) between the number of *Salmonella* and *E. coli*. The number of Petri dishes counted is represented by *n*. For *Salmonella* $n = 4$, except on days 1 ($n = 3$) and 2 ($n = 2$). For *E. coli* $n = 4$, except on day 1 ($n = 3$). The experiment was performed once.

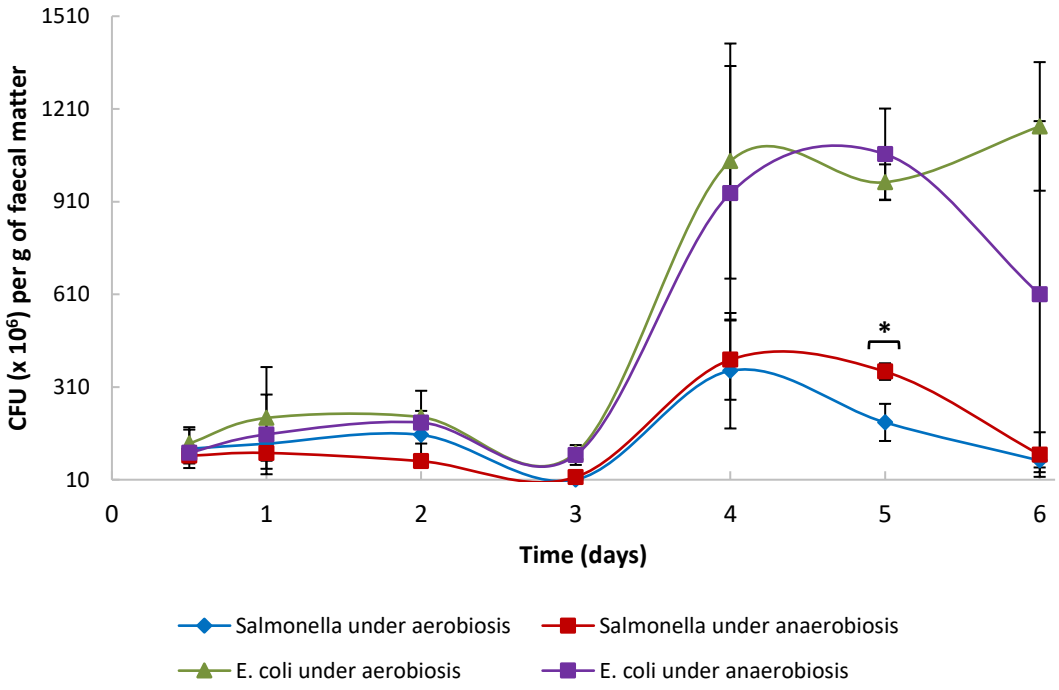


Fig. S9. Growth curves of *Salmonella* Infantis and *E. coli* inoculated in sterile faecal matter, under aerobic and anaerobic conditions. Colonies were counted in MKL. Data shown are means ± SD. Asterisk indicates statistically significant difference (*t*-test, $P < 0.05$) between aerobic and anaerobic growth. The number of Petri dishes counted is represented by *n*. For *Salmonella* $n = 4$, except on day 1 aerobiosis and anaerobiosis, and day 3 anaerobiosis ($n = 3$), day 2 aerobiosis and anaerobiosis ($n = 2$) and day 6 anaerobiosis ($n = 8$). For *E. coli* $n = 4$, except on day 1 aerobiosis and anaerobiosis ($n = 3$), day 2 anaerobiosis ($n = 2$) and day 6 anaerobiosis ($n = 8$). The experiment was performed once.

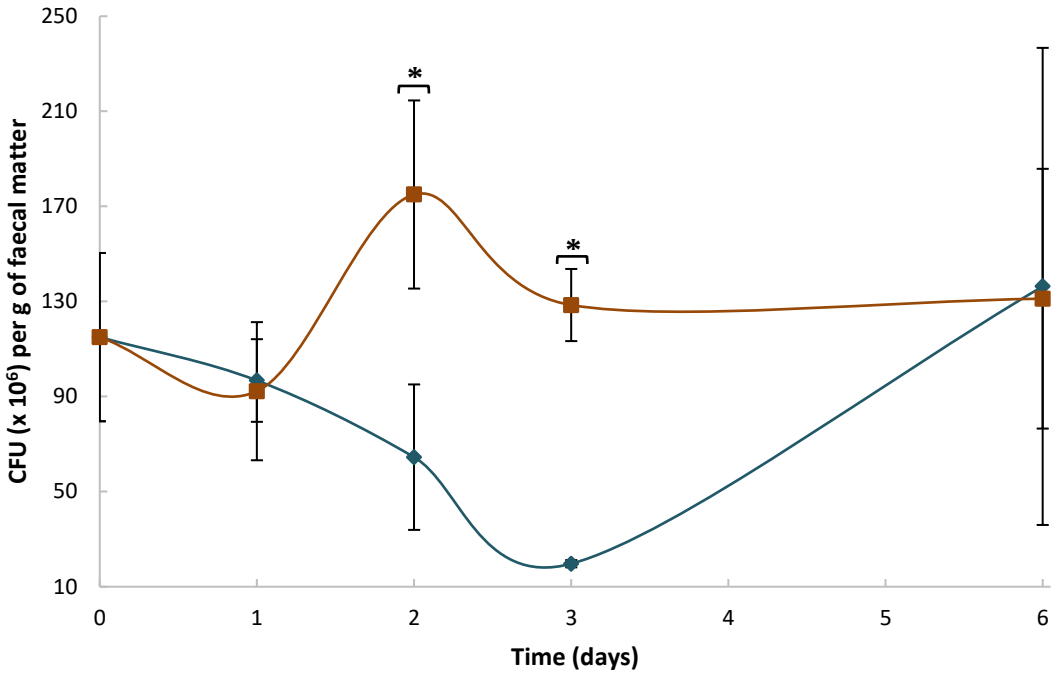


Fig. S10. Growth curves of *Lactobacillus reuteri* rifampicin resistant in chicken faecal matter, under aerobic and anaerobic conditions. Colonies were counted in MRS agar + Rifampicin (100 µg/mL). The brown line corresponds to the growth under anaerobiosis and the blue one, under aerobiosis. Data shown are means ± SD. Asterisks indicate statistically significant difference (*t*-test, $P < 0.05$) between aerobic and anaerobic growth. The number of Petri dishes counted is represented by *n*. For the data points $n = 4$, except for day 3 aerobiosis ($n = 3$) and day 6 ($n = 6$). The experiment was performed once.

Data S1. Experimental Procedures

Overall approach

Five fresh *Salmonella* (isolates from poultry) were inoculated in chicken faecal matter and incubated at room temperature under aerobic and anaerobic conditions. *Salmonella* colonies number was determined by culture and by the loop-mediated isothermal amplification 3M™ Molecular Detection Assay 2 - *Salmonella* (MDA2SAL) (Fig. 1).

The *Salmonella* isolates were identified as *Salmonella enterica* serovars Infantis, Dublin, Heidelberg, Brandenburg and Stanley utilizing a multiplex PCR (Kim *et al.*, 2006). A *Salmonella* Infantis (strain POL 398 B) resistant to nitrofurantoin was used for plate count tests.

Salmonella inoculation in chicken faecal matter

Each *Salmonella* strain was cultured in 4 mL of Brain Heart Infusion broth, then the culture was centrifuged for 5 min at 4,000 x*g*, the supernatant was discarded, and the pellet was re-suspended in 500 μL of sterile saline solution. The process was repeated once to eliminate remnants of culture medium and the resulting suspension was used to inoculate chicken faeces. Before inoculation, the number of *Salmonella* cells per mL of suspension was determined by counting in a Petroff-Hausser chamber.

In a first trial, faecal material was obtained from 3 2-week old broiler chickens *Salmonella* free (analyzed using the loop-mediated isothermal amplification method 3M™ MDA2SAL). The elapsed time between excretion and use in the experiments varied from 0 to 16 h, depending on the amount of faecal matter needed. To reduce the stool aging effect on bacterial growth, all the faecal material collected for each experiment was pooled and mixed.

Faecal matter pooled was split into 10 g aliquots and placed in 35 Petri dishes. In each set of 7 dishes, it was inoculated 100 μL of suspension (10^9 cells per mL) of a *Salmonella* serovar. The

faecal matter of one plate in each set was used for counting at 0 h (i.e., immediately after blending); of the remaining dishes, half were incubated in aerobiosis and a half in anaerobiosis, at room temperature, for 24, 48 and 72 h (Vasco *et al*., 2015). The anaerobic atmosphere was created using BD GasPak™ EZ Anaerobe Gas Generating Pouch System with Indicator.

In a subsequent experiment (trial 2), the procedure was as indicated above, but the incubation was carried out up to 12 days (faecal material for this experiment was obtained from another 3 2-week old broiler chickens *Salmonella* free; in this trial, chickens received different diet).

Colony counts

In the first trial (three days), two dishes containing faecal matter inoculated with *S.* Infantis incubated under aerobic and anaerobic conditions was subjected to colony count in culture media for *Salmonella*, *E. coli*, and coliforms. Briefly, after 24-h incubation, we diluted the contents of each Petri dish (up to 10^{-8} in buffered peptone water, BPW), and plated dilutions 10^{-6}, 10^{-7} and 10^{-8} onto Xylose Lysine Deoxycholate Agar (XLD) and XLD with nitrofurantoin (NIT) (12 mg/L) (Sandegren *et al*., 2008) (we took advantage of the *Salmonella* strain's resistance to nitrofurantoin to facilitate *Salmonella* colony count). Typical *Salmonella* colonies were counted in XLD and XLD with NIT to ensure that the fitness of the bacteria was not affected in the medium with an antibiotic. *Salmonella* counts were similar in both media. These three dilutions were also inoculated onto 3M™ Petrifilm E. coli/Coliform Count Plates and incubated for 24 and 48 h at 37 °C, to determine the number of endogenous *E. coli* and coliforms. We counted blue colonies with gas (*E. coli*) and red colonies with gas (other coliforms). The number of total coliforms corresponded to the sum of the blue and red colonies associated with gas. For each treatment, it was included and analyzed a faecal sample without *Salmonella* as a control.

In the second trial, *S.* Infantis colonies were counted in XLD and XLD with NIT up to 12th day (dilutions 10^{-4} to 10^{-8}). Yellow colonies of lactose fermenting bacteria that grew in XLD with NIT were inoculated in Chromocult Agar to determine *E. coli* and coliform counts.

Calculation of specific growth rate, μ

The specific growth rate (μ) was calculated using the formula:

$$\mu = \frac{2.3 \log (\frac{N}{No})}{\Delta t}$$

where N is the final population after a time interval of incubation, Δt, and No is the initial population (Maier, 2009; Montville *et al.*, 2012).

Molecular detection

The number of *Salmonella* cells in the chicken faecal matter at different time points was also determined by the loop-mediated isothermal amplification method 3M™ MDA2SAL. A calibration curve (Gandelman *et al.*, 2010) was carried out using bacteria suspended in stool sample; bacterial cell suspensions (10^{-2} to 10^{-10}) were prepared in a 1:10 dilution of faecal matter in BPW. Additionally, for each trial, we run a suspension with a known number of cells (Petroff-Hausser chamber) of the strain analyzed. A 10^9 cells/mL suspension of each of the 5 different *Salmonella* serovars (Infantis, Dublin, Heidelberg, Brandenburg, and Stanley) inoculated in fresh faecal matter was monitored during days 0, 1, 2 and 3. We used a regression equation to calculate the concentration of *Salmonella* cells at each time point (Gandelman *et al.*, 2010).

Inoculation of Salmonella and E. coli in sterile faecal matter

Similar concentrations (10^9 cells) of *E. coli* (isolated from chicken faeces) and *S.* Infantis were inoculated in sterile (autoclaved) chicken faecal matter and incubated at room temperature in

aerobiosis and anaerobiosis as described above and bacterial growth was monitored daily after (12 hours to 6 days); colonies were counted in MKL.

Anaerobic growth

To test the anaerobic conditions in faecal matter, a *Lactobacillus reuteri* rifampicin-resistant strain LrRR (López *et al.*, 2019) was used. A suspension of LrRR cells (10^9 cells/mL counted in Petroff-Hausser chamber) was inoculated in chicken faecal matter as was indicated above and incubated at room temperature for 0, 1, 2, 3 and 6 days under aerobic and anaerobic conditions. Dilutions were prepared in peptone water 0.1%, inoculated onto Man Rogosa Sharpe agar (MRS) with rifampicin (100 µg/mL) (Miller, 1992) and incubated at 37 °C for 72 h under microaerophilic conditions. Typical colonies of LrRR were counted and analyzed by Gram stain, catalase and oxidase tests (López *et al.*, 2019).

Statistic analysis

Our null hypothesis (H_0) was that there is no significant difference in the growth of *Salmonella* in chicken faecal matter under aerobic and anaerobic conditions, and the alternative hypothesis (H_1), that there is a significant difference. To evaluate them, we performed the *t*-test (two-tailed) for two samples assuming equal variances, with a significance level of 0.05.

References

Gandelman, O.A., Church, V.L., Moore, C.A., Kiddle, G., Carne, C.A., Parmar, S., *et al*. (2010). Novel bioluminescent quantitative detection of nucleic acid amplification in Real-Time. *PLoS ONE* **5:** 13.

Kim, S., Frye, J.G., Hu, J., Fedorka-Cray, P.J., Gautom, R., and Boyle, D.S. (2006). Multiplex PCR-based method for identification of common clinical serotypes of *Salmonella enterica* subsp. *enterica*. *J Clin Microbiol* **44:** 3608–3615.

López, L., Calderón, D., Cardenas, P., Prado, M.B., Valle, C., and Trueba, G. (2019). Evolutionary changes of an intestinal *Lactobacillus reuteri* during probiotic manufacture. *MicrobiologyOpen* **9:** e972

Maier, R.M. (2009). Bacterial Growth. In Maier, R.M., Pepper, I.L., and Gerba, C.P. (eds),

Environmental Microbiology, pp. 37-54.

Miller, J. H. (1992). *A short course in bacterial genetics: A laboratory manual and handbook for Escherichia coli and related bacteria*. Plainview, NY: Cold Spring Harbor Laboratory Press.

Montville, T., Matthews, K., and Kniel, K. (2012). *Food Microbiology. An Introduction* (3rd. ed). Washington, DC: ASM Press.

Sandegren, L., Lindqvist, A., Kahlmeter, G., and Andersson, D.I. (2008). Nitrofurantoin resistance mechanism and fitness cost in *Escherichia coli. Journal of Antimicrobial Chemotherapy*, 62(3), 495–503.

Vasco, G., Spindel, T., Carrera, S., Grigg, A., and Trueba, G. (2015). The role of aerobic respiration in the life cycle of *Escherichia coli*: public health implications. *Avances Cienc Ingenier* **7:** B7–B9.

CHAPTER 3

Use of bacteriophages to control *Salmonella* in poultry operations

Abstract

Antimicrobial resistance is a growing global public health problem; for this reason, the World Health Organization has recommended against the use of antibiotics as growth promoters in animal husbandry. Antibiotics are also used routinely to control *Salmonella* in chickens which are frequent carriers of this pathogen. In Latin America, the most frequent serotypes in chicken products are Enteritidis and Infantis, evidencing numerous reports of multidrug-resistant isolates. To diminish the use of antibiotics, the poultry industry seeks alternatives to reduce nontyphoidal *Salmonella* in chicken meat and one option is the use of bacteriophages. In this context, the objectives of this project were to isolate lytic *Salmonella* bacteriophages from environmental samples, and to define the best phage application method to eliminate the pathogen in chickens from a commercial farm. *Salmonella* bacteriophages were isolated from river water and samples related to poultry production (chicken bedding samples, and water from different points of poultry slaughter and processing plants). Then, the most lytic candidates were evaluated for on-farm application. Oral phage administration (with drinking water) in combination with bedding spray of phages eliminated *Salmonella* from chicken intestine for 10 days. Our results suggest that the use of bacteriophages to control *Salmonella* in poultry industry is a viable and safe alternative to the use of antibiotics.

Introduction

Antimicrobial resistance (AMR) is an increasing global public health problem; for this reason, the World Health Organization rejects the use of antibiotics as growth promoters in animal

husbandry, in order to preserve the effectiveness of important antibiotics in human medicine. This decision was made considering that up to 80% of the consumption of antibiotics of medical importance was destined for animal husbandry (WHO, 2021). Consistent with this concern, the poultry industry seeks alternatives to combat bacteria that are pathogenic for chickens and humans (Wessels, Rip & Gouws, 2021).

Foodborne salmonellosis outbreaks are a global public health problem that is exacerbated by AMR. Therefore, alternative methods are being used in poultry husbandry to reduce the presence of nontyphoidal *Salmonella* (NTS), including the use of compounds with chlorine and organic acids, although their disadvantage is that they affect the sensory properties of the meat (Wessels *et al*., 2021). An interesting option is bacteriophages, viruses that adhere to specific receptors on the bacterial cell wall, so they are considered non-pathogenic for humans and Generally Recognized As Safe (GRAS) for consumption. For the successful implementation of its use, it is necessary to take into account factors such as local legislation and application volumes and concentrations (Hagens & Loessner, 2010; CDC, 2021; Wessels *et al*., 2021).

Bacteriophages (hereinafter called phages) are classified according to their morphology, nucleic acid (ssRNA, dsRNA, ssDNA, and dsDNA), life cycle, and bacterial host (Żbikowska, Michalczuk & Dolka, 2020). Their replication cycle can be lytic (virulent phages) or lysogenic (tempered phages); and some phages have both the lytic and lysogenic cycles. In the lytic cycle, the phages replicate inside the host bacteria and release their progeny killing the host cell to infect new bacteria. In the lysogenic cycle, the genetic material of the phage is integrated into the bacterial chromosome, being vertically transmitted to the bacterial offspring (Wernicki, Nowaczek & Urban-Chmiel, 2017; Żbikowska *et al*., 2020). The integrated phage or prophage can become activated and enter a lytic cycle under stress conditions (Wernicki *et al*., 2017; Żbikowska *et al*., 2020; Wessels *et al*., 2021).

Most of the phages described, including *Salmonella* phages, belong to the order *Caudovirales* (they have a tail) that includes the families *Siphoviridae* (long non-contractile tail), *Myoviridae* (long contractile tail), and *Podoviridae* (short non-contractile tail); its size ranges between 20 and 200 nm (Dion, Oechslin & Moineau, 2020; Żbikowska *et al*., 2020).

Lytic phages are specially sought in the food industry because tempered phages, by inserting their genome into the bacterial chromosome, could alter the phenotype of the bacterial host (lysogenic conversion), and sometimes could increase bacterial pathogenicity (Hagens & Loessner, 2010; Fillol-Salom *et al*., 2019).

The first record of phages used to eliminate *Salmonella* in poultry dates from 1917, when D'Herelle developed a phage therapy against fowl typhoid by *Salmonella enterica* serovar Gallinarum in chickens (Wernicki *et al*., 2017). Since then, the phage application in the poultry industry is increasingly widespread. Some examples in American countries are cited in Table 1.

However, a major limitation of phage use is that bacteria could develop resistance to phages by: (1) Preventing phage adsorption by means of blocking of phage receptors, production of extracellular matrix or production of competitive inhibitors; (2) preventing phage DNA entry into host cells, using the superinfection exclusion (Sie) systems (blocking proteins); (3) cutting phage nucleic acids by mean of restriction-modification systems or the CRISPR-Cas system; and (4) developing abortive infection systems that typically target a crucial step of phage multiplication such as replication, transcription or translation (Labrie, Samson & Moineau, 2010). Phage resistance in *S.* Typhimurium was found to be related to reduce LPS production and thus lower availability of the phage receptor for adsorption (Wang *et al*., 2019).

In Ecuador, *Salmonella* is present in 88% of chicken carcasses, where 91% of strains are multidrug-resistant (MDR). 94% of the isolates belong to serovar Infantis (Vinueza-Burgos *et al*., 2019). To reduce the use of antimicrobials, some poultry farms have explored the possibility

of using phages. The objectives of this project were to isolate *Salmonella* phages from environmental samples (river water and samples related to poultry production), and to define the best phage application method to eliminate *Salmonella* in chickens from a commercial farm.

Methods

Strains

Salmonella enterica serovar Typhimurium ATCC 14028, *Salmonella enterica* from poultry farms (serovars Infantis, Braenderup, and Saintpaul), and *Salmonella enterica* serovar Infantis from raw chicken meat were used to isolate phages. *Salmonella enterica* from chicken bedding (serovars Infantis, Braenderup, Saintpaul, and Albany) and from raw chicken meat (serovars Infantis, Brandenburg, Dublin, Heidelberg, Stanley, and Typhimurium), *Salmonella enterica* serovar Infantis from chicken skin and from chicken caeca, and *Salmonella enterica* serovar Amsterdam from animal feed, were used to determine the phages host range.

Escherichia coli from chicken bedding, and *Citrobacter werkmanii* and *Edwardsiella tarda* from a poultry slaughter plant were also used for phages host range tests. The bacterial cultures were stored at -80 ºC in skim milk with 10% glycerol.

Media and buffers

BHI: Brain heart infusion broth (BD, France). Suspend 37 g of the medium in one liter of distilled water; mix, boil for one minute until complete dissolution, and sterilize at 121 °C for 15 minutes. DSPB (Decca Strength Phage Broth): Mix peptone 100 g, yeast extract 50 g, K_2HPO_4 80 g, and distilled water 1000 mL; pH was adjusted to 7.6 after sterilizing the medium in autoclave (121 °C for 15 minutes). Phage buffer: 10 mM Tris-HCl (pH 7.5), 68.5 mM NaCl, 10 mM $MgSO_4$, 1 mM $CaCl_2$; an autoclave step was realized (121 °C for 15 minutes) separately for each solution and then mixed. Semi-solid agar with Mg: Suspend BHI + 0.7% agar + 0.2% $MgSO_4$ in distilled water, boil to complete dissolution, sterilize for 15 min at 121 °C, and keep

molten (in a 50 °C water bath) until use. Skim milk with glycerol: Mix 10% skim milk and 10% glycerol in distilled water, dispense 1 mL into microtubes, and sterilize for 15 min at 121 °C. Solid agar with Mg: Suspend BHI + 1.5% agar + 0.2% $MgSO_4$ in distilled water, boil to complete dissolution, sterilize for 15 min at 121 °C, and dispense into Petri dishes. Solid nutrient agar: Suspend BHI + 1.5% agar in distilled water, boil to complete dissolution, sterilize for 15 min at 121 °C, and dispense into Petri dishes (Benson, 1980; Piuri, 2019).

Samples for phage isolation

Phages were isolated from the following samples: Wastewater from Machángara and San Pedro rivers (located in Quito, Ecuador), chicken bedding samples, water from different points of a poultry slaughter plant (pre-chiller, chiller, scalder, gutting machine, and final poultry washing), washing water from poultry cutting and marinating machines (Fig. 1 and Table S1).

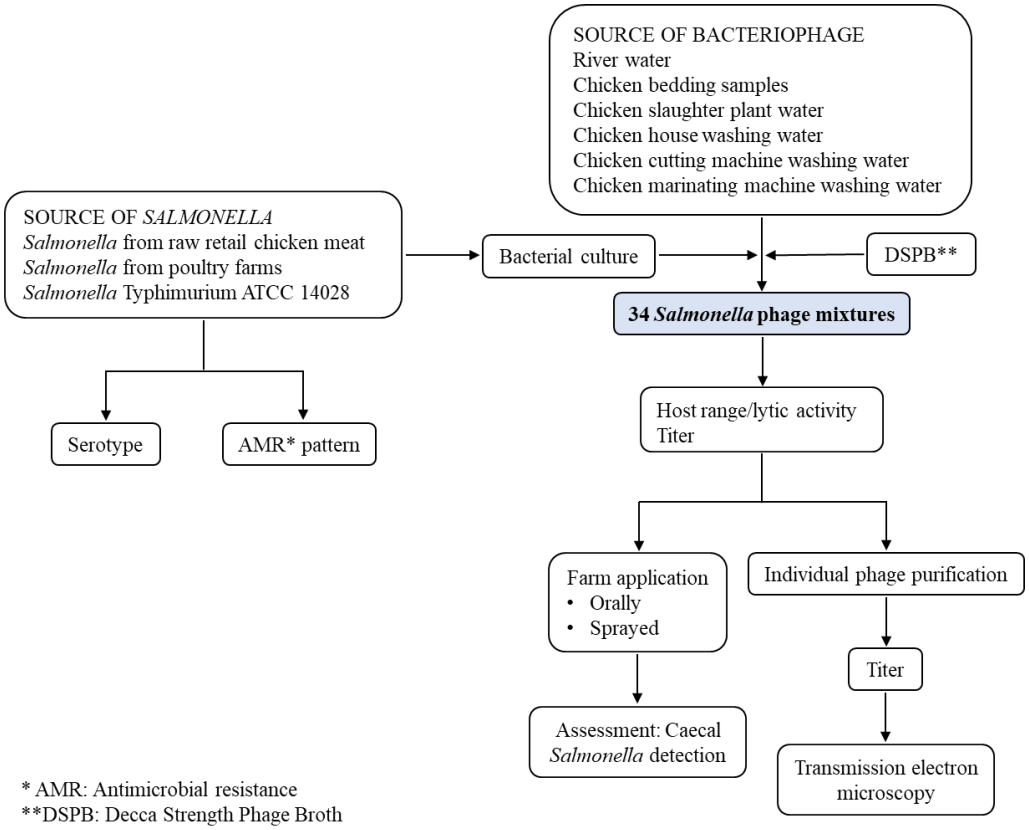


Figure 1. Scheme of the experimental procedures of phage isolation and on-farm application.

Isolation of Salmonella phages

The Benson procedure was followed for phages isolation. Briefly, 45 mL of water sample or 1:1 suspension of chicken bedding sample in sterile distilled water was mixed with 5 mL of 12-16 h *Salmonella* culture in BHI and 5 mL of DSPB and incubated at 37 °C for 24 h. Then, the suspension was centrifuged at 7000 *xg* for 15 minutes and filtered using a 0.45 µm membrane, retaining bacteria and only phage pass through the filter. The phage filtrate was preserved by adding chloroform (3 chloroform drops per 5 mL of culture, or 3%) (Benson, 1980).

DNA extraction from Salmonella isolates and serotyping

DNA extraction from *Salmonella* isolates was done by boiling for 10 minutes a suspension of 3-5 colonies of a pure culture from solid nutrient agar (Dashti *et al*., 2009) in PCR water. Then, a 1/100 dilution of the DNA was made also in PCR water, and serotyping was carried out. The method described by Kim and colleagues was followed to serotype *Salmonella* isolates. Briefly, it consisted in two multiplex PCRs that discriminate 30 serotypes of *S. enterica* subsp. *enterica*. 6 genetic loci of *Salmonella enterica* serovar Typhimurium (STM1-STM6) and 4 of *Salmonella enterica* serovar Typhi (STY1-STY4) were used. Of the 30 serotypes that can be discriminated, 22 present unique amplification patterns, and 8 are grouped into 4 pairs. To resolve these pairs, 2 additional PCRs can be performed (primer sets STM7 and PT4-1; the latter based on genomes of Enteritidis and Dublin serovars) (Kim *et al*., 2006).

Antimicrobial resistance of Salmonella isolates

Antibiogram of the *Salmonella* isolates was carried out, following the Kirby-Bauer Disk Diffusion Susceptibility Test Protocol. The antimicrobials tested were amoxicillin-clavulanic acid (AMC- 20/10 µg), ampicillin (AM-10 µg), azithromycin (AZM-15 µg), cefotaxime (CTX-30 µg), ceftriaxone (CRO-30 µg), chloramphenicol (C-30 µg), ciprofloxacin (CIP-5 µg), gentamicin (GM-10 µg), nalidixic acid (NA-30 µg), tetracycline (TE-30 µg), streptomycin (S-

10 µg), and sulphamethoxazole-trimethoprim (SXT-23.75/1.25 µg) (Hudzicki, 2009; CLSI, 2021). The trial was performed once (n = 1).

Phages host range and lytic activity

Phage host range was determined by spotting the phage mixtures on a lawn of each of the 38 *Salmonella* isolates and 3 other isolates from *Enterobacteriaceae* family (*E. coli*, *C. werkmanii*, and *E. tarda*). Briefly, a logarithmic phase culture (12-16 h) of each test isolate was spread on the surface of a solid agar with Mg, 2 µL of each phage mixture was placed in a cell of a grid drawn on the Petri dish and incubated at 37 °C for 24 h. Then, the phages lytic activity was evaluated, rating their virulence level according to the following scale: 4, complete clearing; 3, total clearing with pinpoint colonies within the plaques; 2, turbidity throughout the cleared zone; 1, a few individual plaques; 0, no clearing (Huang *et al*., 2018).

Phage titer

To determine the titer of the phage mixtures and the individual phages, the double-layer agar (DLA) technique was used. Serial dilutions (10^{-1} to 10^{-10}) of phage suspensions were made in phage buffer. 4 mL of semi-solid agar with Mg was mixed with 300 µL of *Salmonella* culture and poured on the surface of solid nutrient agar. Once the agar solidified, 2 µL of phage dilution was placed in each cell of a grid drawn in the Petri dish and incubated at 37 °C for 24 h. The phage titer, in plaque forming units (PFU) per mL, was calculated with the formula: PFU/mL = Number of lysis plaques / (Inoculum volume (mL) x Dilution) (Piuri, 2019).

Phage application in poultry farms

The most lytic phage mixture against *Salmonella* (M-115A) was used for on-farm application. In preliminary essays, the volume and the conditions of phages administration to chickens together with the drinking water were defined. In the first trial, the phages were administered orally to chickens within houses that previously tested positive for *Salmonella*. The phage administration was done with the drinking water in a 1000:0.2 water:phage ratio, after 2 h of

water supply suspension, together with the viral protector VAC-PAC PLUS®, that stained the water blue, to control that all the chickens drink it. In the second trial, the application was carried out orally and by spraying the phages dissolved in water, using hand pumps, on the chicken bedding. On day 1, orally and by spraying, and on days 2 and 3 only by spraying (Clavijo *et al*., 2019; Coba, 2020). To assess the phages effectiveness, on each sampling day, 25 g of a pool of caeca of 25 randomly sampled chickens was analyzed to detect *Salmonella*. These analyzes were carried out in the Bacteriology Laboratory of the Faculty of Veterinary Medicine and Zootechnics, Universidad Central del Ecuador, based on the ISO 6579 Standard.

Individual phages purification

Individual phages from a mixture were purified using the DLA technique. Briefly, 300 µL of a log phase *Salmonella* culture and 300 µL of each decimal dilution of the phage suspension (10^{-4} to 10^{-8}) were left in contact for 10 minutes, then, molten semi-solid agar with Mg (top agar) was added, and the mixture was poured onto a solid nutrient agar (bottom agar) surface and incubated at 37 ºC for 24 hours. The following day, the number of lysis plaques was counted to calculate the phage titer and a lysis plaque was taken with a sterile toothpick, resuspended in 150 µL of phage buffer and labeled as "1st purification". The process was repeated 5 consecutive times to purify the individual phages, and the microtubes with the suspension of the lysis plaques were refrigerated (4 ºC), labeled with the corresponding purification. The phage suspension resulting from the last purification was titrated (Clockie & Kropinski, 2009; Piuri, 2019).

Transmission electron microscopy

A transmission electron microscope (TEM) (Tecnai G2 Spirit Twin, FEI, Holland) operated at 80 kV was used to observe phages. Tungstophosphoric acid (PTA) purchased from Ted Pella was prepared at 0.5% (w/v) aqueous solution, adjusted pH 7. Single-droplet negative staining technique was applied on our semipurified aqueous suspension, and formvar (thermoplastic

resin) support films (300 mesh) were used (Kuo, 2007). These analyzes were carried out in the Nanomaterials Characterization Laboratory, CENCINAT, Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador. The phages size in the micrographs was evaluated using FIJI software (ImageJ 1.53f51) (Schindelin *et al*., 2012).

Results

Salmonella phage mixtures isolation

In total, 34 phage mixtures were isolated from 7 types of samples; the *Salmonella* host isolates came from poultry farms and raw retail chicken meat, in addition to the *Salmonella* Typhimurium ATCC 14028 strain. Table 2 and Fig. 2 show how many phage mixtures were isolated from each type of sample and the origin of the host bacterium.

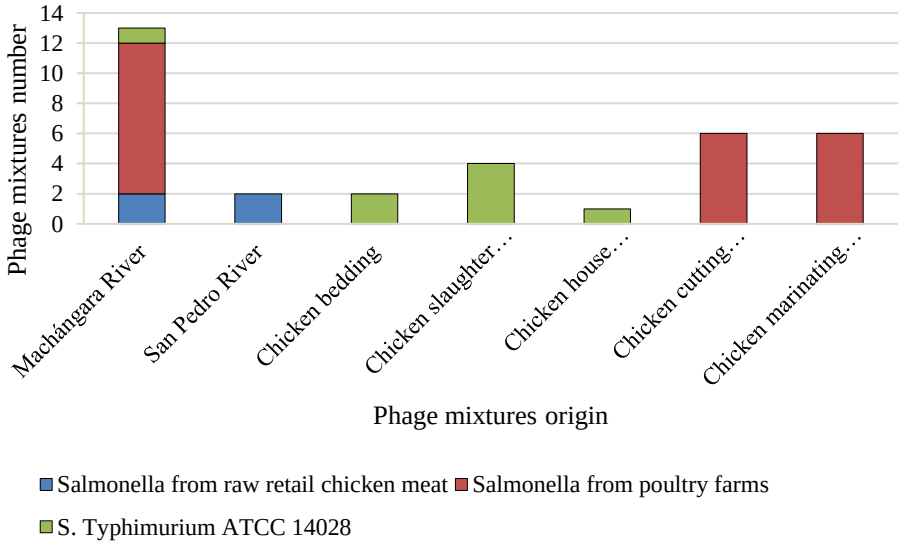


Figure 2. Origin and number of the isolated *Salmonella* phage mixtures. The X-axis shows the source of the phages. The colors of the bars indicate the origin of the host *Salmonella* isolate.

Origin and serovars of Salmonella isolates

The lytic activity of *Salmonella* phage mixtures was tested *in vitro* against 38 *Salmonella* isolates obtained from chicken caeca and skin, raw retail chicken meat, chicken bedding and animal feed (Fig. 3).

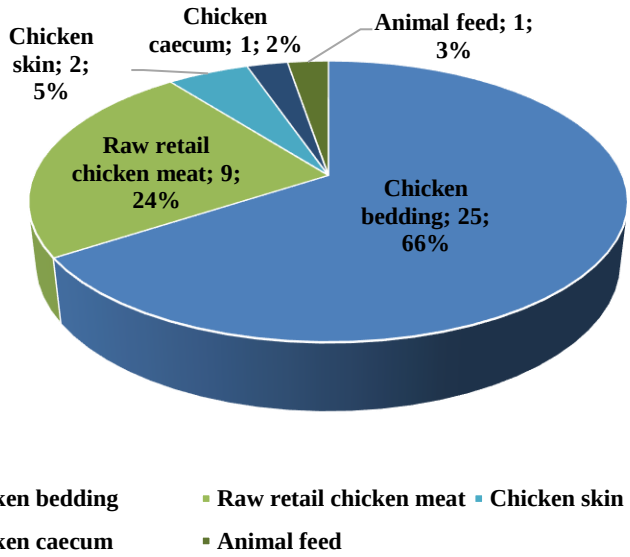


Figure 3. *Salmonella* isolates origin. This graph shows the origin of the 38 *Salmonella* isolates tested with the isolated phages.

The *Salmonella* isolates that could be serotyped belong to 10 serovars, the majority being Infantis (66%) (Fig. 4).

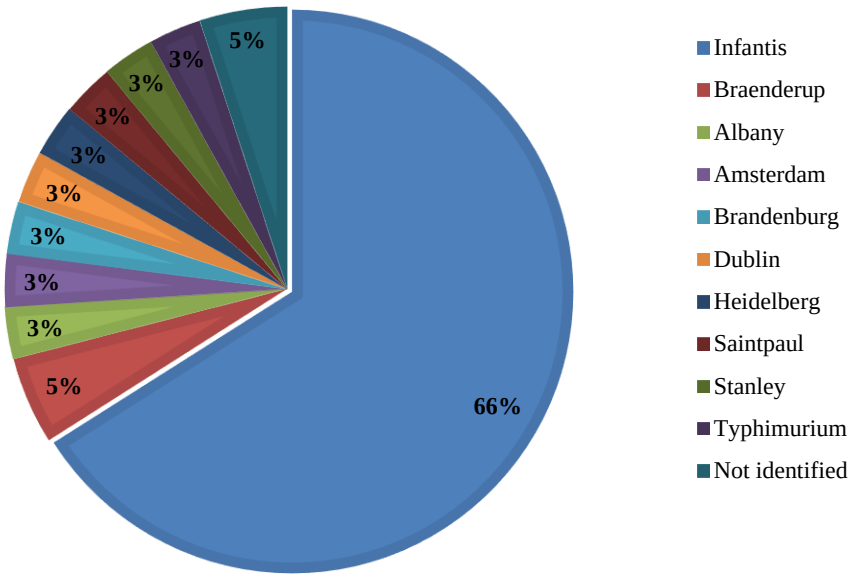


Figure 4. *Salmonella* serovars. This graph shows the serovar distribution of the 38 *Salmonella* isolates tested with phages.

Antimicrobial resistance patterns of Salmonella isolates

Of the 38 *Salmonella* isolates tested, 31 (82%) were MDR. For serovar Infantis, which was the most frequent, 96% of the isolates (24/25) were MDR. The serotypes that showed a pattern of susceptibility to the antimicrobials used were Braenderup, Saintpaul, Amsterdam and Albany. Table 3 shows the antimicrobial resistance patterns of the *Salmonella* isolates, and Fig. 5 also shows their origin.

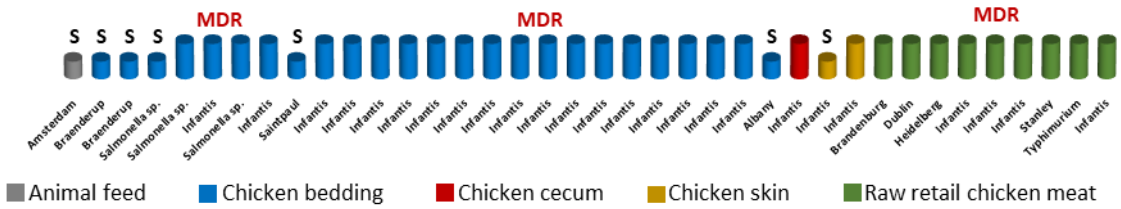


Figure 5. Antimicrobial resistance patterns and origin of *Salmonella* isolates.

Host range of the isolated phages

The isolated phages showed lytic activity *in vitro* against 84% of the *Salmonella* isolates, and different virulence levels. For on-farm application, the phage mixture M-115A was used, which presented the highest levels of virulence against *Salmonella* isolates (Figs. 6A and 6B).

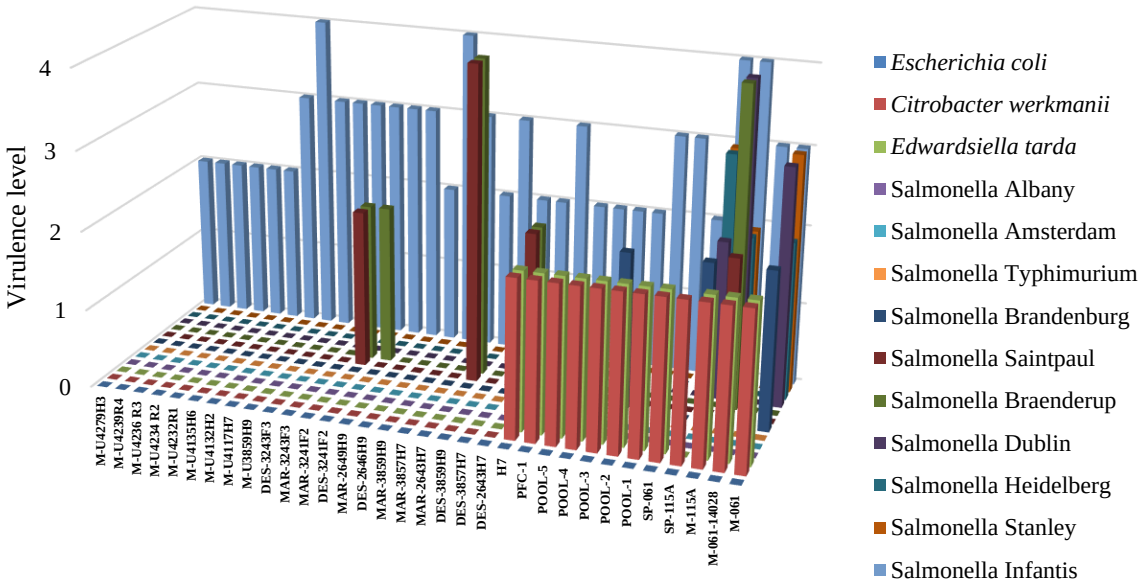


Figure 6A.

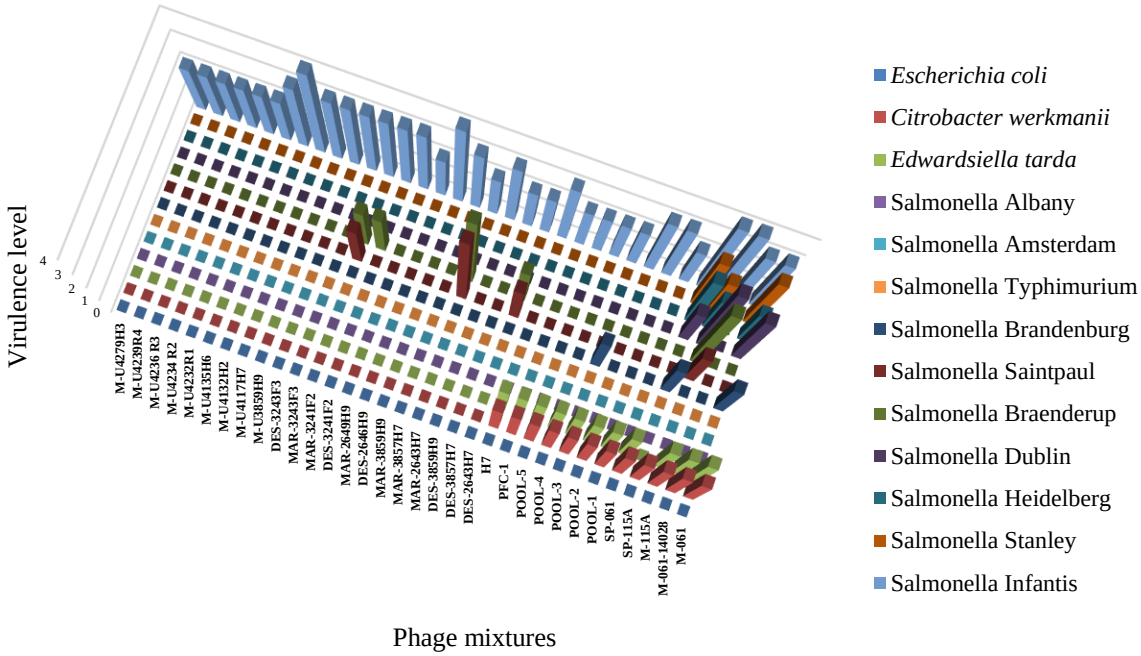


Figure 6B.

Figure 6. Host range of *Salmonella* phage mixtures. Virulence scale: 4, Complete clearing; 3, total clearing with pinpoint colonies within the plaques; 2, turbidity throughout the cleared zone; 1, a few individual plaques; 0, no clearing (Huang *et al*., 2018). *Escherichia coli* was isolated from poultry bedding; *Citrobacter werkmanii* and *Edwardsiella tarda*, from a poultry slaughter plant.

Phage-resistant Salmonella isolates

Seven *Salmonella* isolates belonging to serovars Infantis, Albany, Amsterdam, Brandenburg, and Typhimurium were phage-resistant. Table 4 shows the characteristics of these isolates.

Effectiveness of the on-farm application of phages

In the first trial, phages were administered orally with drinking water to chickens from houses that were positive for *Salmonella*. The analysis of the chickens' caecum on day 3 after phage application was negative for *Salmonella*, but on day 9 the presence of the pathogen was detected in the poultry intestine (Fig. 7).

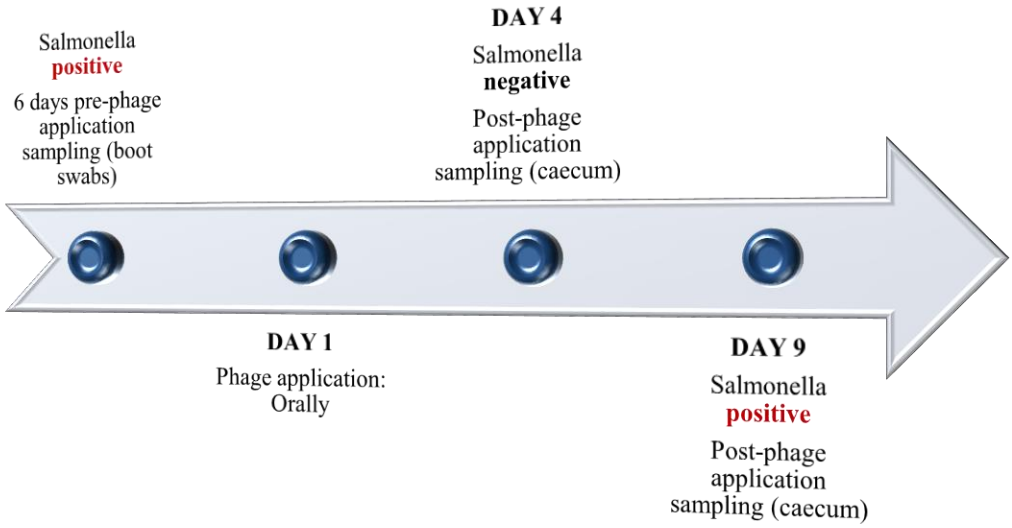


Figure 7. Results of the first trial of on-farm phage application. Phage application effectiveness over time**.** One application route: Orally (with drinking water).

In the second trial, the phage application was carried out orally with drinking water, and by spraying in the chickens bedding. In this trial, the analysis of the chickens' caecum was negative for *Salmonella* in the samples taken on days 4 and 10 (Fig. 8). The latter corresponded to the slaughter age of the chickens (42-day old).

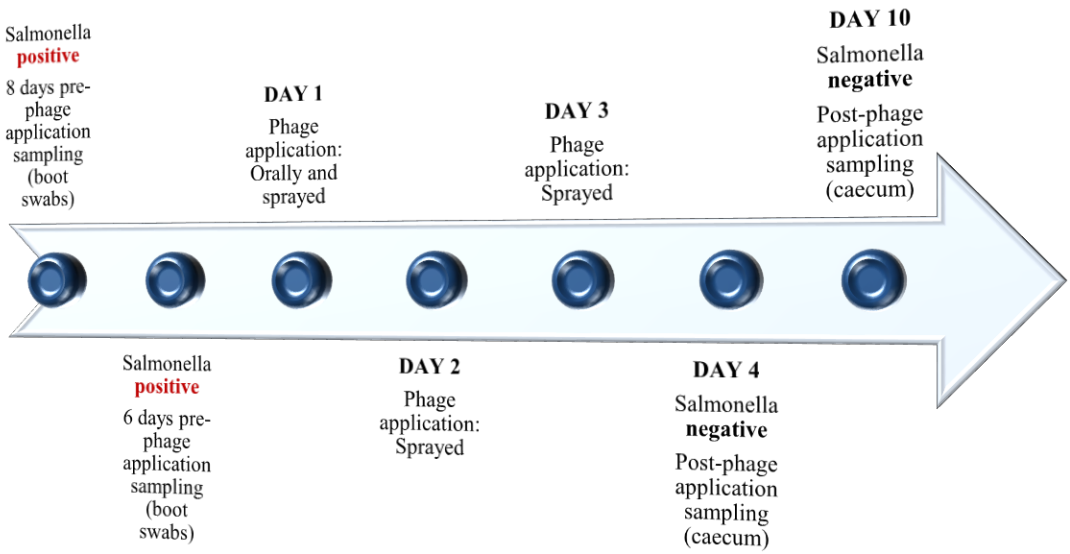
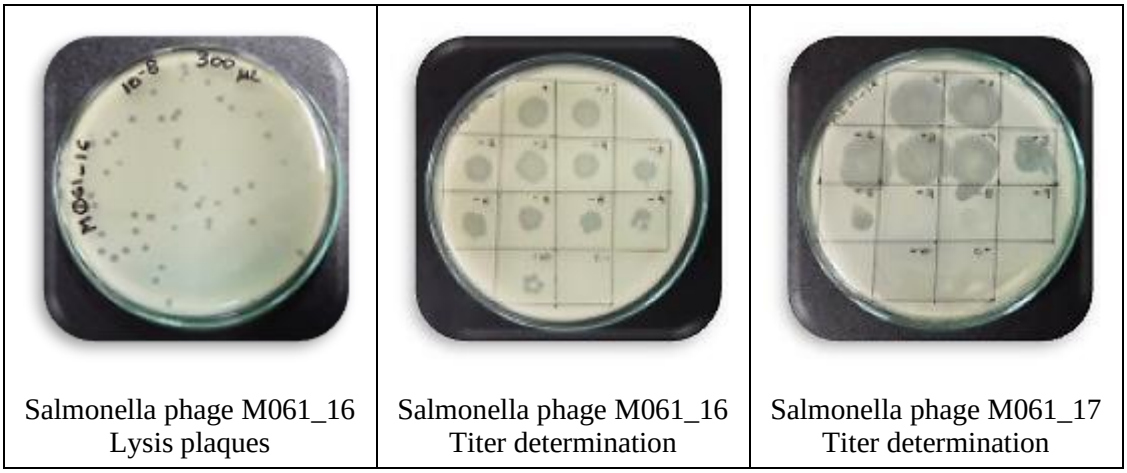


Figure 8. Results of the second trial of on-farm phage application. Phage application effectiveness over time**.** Two application routes: Orally (with drinking water) and sprayed.

Purification of individual phages from a mixture

The individual phages of the M-061 mixture were purified. Two phages were obtained, named as Salmonella phage M061_16 y Salmonella phage M061_17 (Adriaenssens & Brister, 2017). On the DLA, these phages showed lysis plaques with complete clearance (virulence grade 4) (Huang *et al*., 2018), and titers of 10^{12} PFU/mL for Salmonella phage M061_16, and 10^{8} PFU/mL for Salmonella phage M061_17 were obtained (Fig. 9).



Salmonella phage M061_16 Lysis plaques	Salmonella phage M061_16 Titer determination	Salmonella phage M061_17 Titer determination

Figure 9. Lytic activity and titer of individual phages. Left: Lysis plaques of Salmonella phage M061_16 suspension. Center and right: Titer spot test of Salmonella phage M061_16 and Salmonella phage M061_17 suspensions.

Transmission electron microscopy

In the micrograph of Salmonella phage M061_16 one morphology was observed, while in that of Salmonella phage M061_17, more than one morphology, evidencing more than one type of phage in the sample. For the classification of the observed phages, the following parameters were determined: head length (hl; along the axis of the tail), head diameter (hd; width perpendicular to the tail), tail length (tl) and tail diameter (td). Particles with tl <40 nm were classified as *Podoviridae*, and the td value was used to classify viruses with longer tails as *Myoviridae* (td ≥ 16 nm) or *Siphoviridae* (td <16 nm) (Ackermann, 1999; Jurczak-Kurek *et al*., 2016). Phages of the *Podoviridae* family, of different sizes, were observed in the Salmonella phage M061_16 suspension. Phages of the *Siphoviridae* and *Podoviridae* families were observed in the Salmonella phage M061_17 suspension (Table 5).

Discussion

As in other studies, our phages with the best lytic activity were isolated from river water (Machángara) and, because it crosses urbanized and industrial areas, contains wastewater (Higgins *et al*., 2005; Turki *et al*., 2012; Huang *et al*., 2018; Var, Heshmati & AlMatar, 2018). Phages from samples related to poultry operations showed less lytic activity than those from rivers, probably because some of our *Salmonella* isolates are persistent in farms and other poultry processing facilities and could have developed phage-resistance (Wang *et al*., 2019; Liu *et al*., 2021), since the majority (65%) of *Salmonella* hosts for phage isolation come from poultry farms.

Knowing the phages host range is important in predicting how microbial communities shape, virulence genes that could be transferred between bacterial species, and the usefulness of phages in controlling pathogenic bacteria. In nature, phages show a great variability of

specificity, from narrow host ranges within a single species to those that can infect more than one bacterial genus (Koskella & Meaden, 2013). All our phages have a narrow, strain-specific host range (Figs. 6A and 6B) because, although they all infect *Salmonella* Infantis, we had 3 *S.* Infantis isolates phage-resistant (Table 4).

Considering the phage application techniques suggested for commercial products and used in other studies (Table 1), we tested two routes of phage application: oral, with drinking water and by spraying on the chicken bedding. The phage mixture M-115A, which showed the highest lytic activity against *Salmonella* was used for on-farm application. The most effective method of phages application was the combination of two routes: oral with drinking water, and by spraying on the chicken bedding, eliminating *Salmonella* in the chickens' caecum until day 10 (Fig. 8). We attribute the success of the methods combination to two factors: 1) The phage concentration increased in the chickens' house (Hagens & Loessner, 2010), and 2) the phages were applied directly on the chicken bedding, where *Salmonella* was detected (Figs. 7 and 8). When only the oral route was used, the detection of the pathogen was negative on day 4, but it was positive again on day 9 (Fig. 7). Apparently, the pathogen remained in the chicken bedding and reinfected the poultry and may also have been spread by coprophagy (Carvalho *et al*., 2010). But when spraying phages was applied, *Salmonella* was eliminated from the bedding and there was no reinfection of the chickens.

It is inevitable to find bacterial host resistance to phages when using them as antimicrobials (Fong *et al*., 2020). In our *in vitro* tests, seven *Salmonella* isolates showed resistance to the 34 phage mixtures. These isolates belong to different serovars, and come from chicken bedding (4/7), raw retail chicken meat (2/7), and animal feed (1/7); 5 were MDR, while 2 were susceptible to most of the tested antimicrobials (Table 4). Even though there are reports of cross-resistance to phages and antibiotics (Kortright *et al*, 2021), generally the bactericidal

mechanisms are different (Loc-Carrillo & Abedon, 2011), and as far as we know it is not common to find this type of resistance.

Although resistance to lytic phages is not common, increases in the population of phage-resistant *Salmonella* have been reported after continuous exposure, so it is recommended that applications be made shortly before poultry slaughtering (Carvalho *et al*., 2010; Wessels *et al*., 2021). In accordance with this recommendation, our phages on-farm application started only 10 days before chicken slaughter. However, reports of resistance highlight the need for legislation and monitoring the spread of phage-resistant bacteria (Wessels *et al*., 2021).

Our results confirm that phages can be used successfully to control *Salmonella* in commercial poultry farms, which constitutes a viable alternative to the use of antibiotics in this field, as there is worldwide concern about the emergence of MDR *Salmonella* serotypes in the food chain (Nair, Venkitanarayanan & Kollanoor, 2018; Xu *et al*., 2020). This was also evident in our study; among the tested *Salmonella* isolates (whose origin was the poultry industry) a high AMR was found (82%), and among those of the Infantis serotype, 96% was MDR, data that agrees with other reports (García-Soto *et al*., 2020; Mejia, Vela & Zapata, 2020; Tyson *et al*., 2020).

On the other hand, in the current poultry production dynamics, newborn chicks are not exposed to the protective commensal microbiota of adult birds, because they are born in the clean environment of an incubator (Litvak et al., 2019); in this context, the use of phages in chickens is proposed at an early age, to prevent colonization of the intestinal tract with *Salmonella* (Bardina *et al*., 2012).

The purification of individual phages by the DLA technique is based only on the lysis plaques morphology (Piuri, 2019). In our case, the Salmonella phage M061_17 suspension could not be purified by this technique, despite having made 5 successive purifications, unlike other studies in which individual phages were obtained with only 3 purifications (Huang *et al*., 2018;

Hyman, 2019). Electron micrographs allowed us to classify the Salmonella phage M061_16 within *Podoviridae* family, and the phages of Salmonella phage M061_17 suspension, within *Siphoviridae* and *Podoviridae* families (Table 5). Our results coincide with the described *Salmonella* phages, which correspond to the order *Caudovirales* (Bardina *et al*., 2012; Moreno Switt *et al*., 2013; Huang *et al*., 2018; Var *et al*., 2018).

One strength of this research was that because it was carried out in collaboration with a commercial farm, the phages were applied at the age when chickens are usually slaughtered, and our data are easily applicable to other poultry farms.

The present investigation also had limitations: (1) We did not have positive controls, that is, sheds in which *Salmonella* was detected, but no phages were applied; and (2) the efficacy of administering the phages to chickens with drinking water and feed, and different concentration of phage in water, was not compared.

Conclusions

The wastewater from the Machángara and San Pedro rivers, in the city of Quito, was a good source of lytic phages against *Salmonella* strains isolated from the local poultry industry. *In vitro*, our phages were lytic against 82% of the tested *Salmonella* isolates, which belong to the Infantis, Saintpaul, Braenderup, Dublin, Heidelberg, and Stanley serovars. All our phages showed lytic activity against *Salmonella* Infantis, although we had 3 phage-resistant isolates of *S*. Infantis. This serovar is important in poultry production in Ecuador, due to its high prevalence and AMR. We conclude that the use of phages to control *Salmonella* in poultry production is a viable and safe alternative to the use of antibiotics.

References

Ackermann H.W. (1999). Tailed bacteriophages: the order *Caudovirales*. *Advances in virus research, 51*, 135–201.

Adriaenssens, E., & Brister, J.R. (2017). How to Name and Classify Your Phage: An Informal Guide. *Viruses*, *9*(4), 70.

Bardina, C., Spricigo, D.A., Cortés, P., & Llagostera, M. (2012). Significance of the bacteriophage treatment schedule in reducing *Salmonella* colonization of poultry. *Applied and environmental microbiology*, *78*(18), 6600–6607.

Benson H. (1980). *Microbiological applications. A laboratory manual in general microbiology*, 3rd. Ed. Iowa: Wm. C. Brown Company Publishers.

Borie, C., Albala, I., Sánchez, P., Sánchez, M.L., Ramírez, S., Navarro, C., Morales, M.A., Retamales, A.J., & Robeson, J. (2008). Bacteriophage treatment reduces *Salmonella* colonization of infected chickens. *Avian diseases*, *52*(1), 64–67.

Carvalho, C.M., Gannon, B.W., Halfhide, D.E., Santos, S.B., Hayes, C.M., Roe, J.M., & Azeredo, J. (2010). The *in vivo* efficacy of two administration routes of a phage cocktail to reduce numbers of *Campylobacter coli* and *Campylobacter jejuni* in chickens. *BMC Microbiol 10*, 232.

CDC. (2021). *Salmonella*. Retrieved October 18, 2021, from https://www.cdc.gov/*Salmonella*/

Clavijo, V., Baquero, D., Hernandez, S., Farfan, J.C., Arias, J., Arévalo, A., Donado-Godoy, P., & Vives-Flores, M. (2019). Phage cocktail SalmoFREE® reduces *Salmonella* on a commercial broiler farm. *Poultry science*, *98*(10), 5054–5063.

Clokie, M., & Kropinski, A. (Eds.) (2009). *Bacteriophages Methods and Protocols, Volume 1: Isolation, Characterization, and Interactions*. Hatfield, Hertfordshire, UK: Humana Press.

CLSI. (2021). *Performance Standards for Antimicrobial Susceptibility Testing*. 31st ed. CLSI supplement M100. USA: Clinical and Laboratory Standards Institute.

Coba, M. (2020). *Control of Salmonella enterica serovar Infantis colonization using bacteriophages*. Postgraduate degree work to obtain the degree of Master in Microbiology. Universidad San Francisco de Quito, Quito, Ecuador.

Dashti, A., Jadaon, M., Abdulsamad, A., & Dashti, H. (2009). Heat treatment of bacteria: A simple method of DNA extraction for molecular techniques. *Kuwait Medical Journal*, 41, 117-122.

Dion, M.B., Oechslin, F. & Moineau, S. (2020). Phage diversity, genomics and phylogeny. *Nature reviews. Microbiology*, *18*(3), 125–138.

Fillol-Salom, A., Alsaadi, A., de Sousa, J.A.M., Zhong, L., Foster, K.R., Rocha, E.P.C., Penadés, J.R., Ingmer, H., & Haaber, J. (2019). Bacteriophages benefit from generalized transduction. *PLoS Pathog*, *15*(7): e1007888.

Fiorentin, L., Vieira, N.D., & Barioni Júnior, W. (2005). Use of lytic bacteriophages to reduce *Salmonella* Enteritidis in experimentally contaminated chicken cuts. *Braz J of Poultry Science, 7*(4), 255-260.

Fong, K., Mu, K., Rheault, J.G., Levesque, R.C., Kitts, D.D., Delaquis, P., Goodridge, L., & Wang, S. (2020). Bacteriophage-insensitive mutants of antimicrobial-resistant *Salmonella enterica* are altered in their tetracycline resistance and virulence in Caco-2 intestinal cells. *Int J of Molecular Sciences*, *21*(5), 1883.

García-Soto, S., Abdel-Glil, M.Y., Tomaso, H., Linde, J., & Methner, U. (2020). Emergence of multidrug-resistant *Salmonella enterica* Subspecies *enterica* serovar infantis of multilocus sequence type 2283 in German broiler farms. *Frontiers in Microbiology, 11*, 1741.

Goode, D., Allen, V.M., & Barrow, P.A. (2003). Reduction of experimental *Salmonella* and *Campylobacter* contamination of chicken skin by application of lytic bacteriophages. *Appl Environ Microbiol*, *69*(8):5032-6.

Hagens, S., & Loessner, M.J. (2010). Bacteriophage for biocontrol of foodborne pathogens: calculations and considerations. *Curr Pharm Biotechnol*, Jan;11(1):58-68.

Higgins, J.P., Higgins, S.E., Guenther, K.L., Huff, W., Donoghue, A.M., Donoghue, D.J., & Hargis, B.M. (2005). Use of a specific bacteriophage treatment to reduce *Salmonella* in poultry products. *Poult Sci, 84*(7):1141-5.

Huang, C., Virk, S.M., Shi, J., Zhou, Y., Willias, S.P., Morsy, M.K., Abdelnabby, H.E., Liu, J., Wang, X., & Li, J. (2018). Isolation, characterization, and application of bacteriophage LPSE1 against *Salmonella enterica* in ready to eat (RTE) foods. *Frontiers in Microbiology, 9*, 1046.

Hudzicki, J. (2009). Kirby-Bauer disk diffusion susceptibility test protocol. *American Society for Microbiology*, (December), 1–23.

Hyman P. (2019). Phages for Phage Therapy: Isolation, Characterization, and Host Range Breadth. *Pharmaceuticals (Basel, Switzerland), 12*(1), 35.

Jurczak-Kurek, A., Gąsior, T., Nejman-Faleńczyk, B., Bloch, S., Dydecka, A., Topka, G., Necel, A., Jakubowska-Deredas, M., Narajczyk, M., Richert, M., Mieszkowska, A., Wróbel, B., Węgrzyn, G. and Węgrzyn, A. (2016). Biodiversity of bacteriophages: Morphological and biological properties of a large group of phages isolated from urban sewage. *Sci Rep, 6*, 34338.

Kim, S., Frye, J.G., Hu, J., Fedorka-Cray, P.J., Gautom, R., & Boyle, D.S. (2006). Multiplex PCR-based method for identification of common clinical serotypes of *Salmonella enterica* subsp. *enterica*. *J Clin Microbiol, 44*(10), 3608–3615.

Koskella, B., & Meaden, S. (2013). Understanding bacteriophage specificity in natural microbial communities. *Viruses*, *5*(3), 806–823.

Kuo, J. (Ed). (2007). *Electron microscopy: Methods and protocols* (2nd ed.). Totowa, New Jersey: Humana Press.

Labrie, S.J., Samson, J.E., & Moineau, S. (2010). Bacteriophage resistance mechanisms. *Nature Reviews Microbiology*, *8*(5), 317–327.

Litvak, Y., Mon, K.K.Z., Nguyen, H., Chanthavixay, G., Liou, M., Velazquez, E.M., Kutter, L., Alcantara M.A., Byndloss, M.X., Tiffany, C.R., Walker, G.T., Faber, F., Zhu, Y., Bronner, D.N., Byndloss, A.J., Tsolis, R.M., Zhou, H. and Bäumler, A.J. (2019). Commensal *Enterobacteriaceae* protect against *Salmonella* colonization through oxygen competition. *Cell Host Microbe*, *25*(1):128-139.

Liu, R., Li, Z., Han, G., Cun, S., Yang, M., & Liu, X. (2021). Bacteriophage ecology in biological wastewater treatment systems. *Applied microbiology and biotechnology*, *105*(13), 5299–5307.

Loc-Carrillo, C., & Abedon, S.T. (2011). Pros and cons of phage therapy. *Bacteriophage*, *1*(2), 111–114.

Mejia, L., Vela, G., & Zapata, S. (2020). High occurrence of multiresistant *Salmonella* Infantis in retail meat in Ecuador. *Foodborne pathogens and disease*, *18*(1), 41–48.

Moreno Switt, A.I., Orsi, R.H., den Bakker, H.C., Vongkamjan, K., Altier, C., & Wiedmann, M. (2013). Genomic characterization provides new insight into *Salmonella* phage diversity. *BMC genomics*, *14*, 481.

Nair, D., Venkitanarayanan, K., & Kollanoor, J.A. (2018). Antibiotic-resistant *Salmonella* in the food supply and the potential role of antibiotic alternatives for control. *Foods*, *7*(10):167.

Piuri, M. (2019). *Los bacteriófagos: del genoma al metagenoma* [Bacteriophages: From the genome to the metagenome]. Buenos Aires: Departamento de Química Biológica, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires.

Rogovski, P., Silva, R.d., Cadamuro, R.D., Souza, E.B.d., Savi, B.P., Viancelli, A., Michelon, W., Tápparo, D.C., Treichel, H., Rodríguez-Lazaro, D., & Fongaro, G. (2021). *Salmonella* enterica serovar Enteritidis control in poultry litter mediated by lytic bacteriophage isolated from swine manure. *Int J Environ Res Public Health*, *18*, 8862.

Schindelin, J., Arganda-Carreras, I., Frise, E., Kaynig, V., Longair, M., Pietzsch, T., Preibisch, S., Rueden, C., Saalfeld, S., Schmid, B., Tinevez, J., White, D.J., Hartenstein, V., Eliceiri, K., Tomancak, P., & Cardona, A. (2012). Fiji: An open-source platform for biological-image analysis. *Nat Methods*, *9*, 676–682.

Turki, Y., Ouzari, H., Mehri, I., Ammar, A.B., & Hassen, A. (2012). Evaluation of a cocktail of three bacteriophages for the biocontrol of *Salmonella* of wastewater. *Food Research International, 45*(2), 1099–1105.

Tyson, G.H., Li, C., Harrison, L.B., Martin, G., Hsu, C.-H., Tate, H., Tran, T.-T., Strain, E., & Zhao, S. (2020). A multidrug-resistant *Salmonella* Infantis clone is spreading and recombining in the United States. *Microbial drug resistance*, *27*(6), 792–799.

Var, I., Heshmati, B., & AlMatar, M. (2018). Isolation and identification of *Salmonella* bacteriophage from sewage waters. *J Biotechnol Science Research, 5*(2):1-8

Vinueza-Burgos, C., Baquero, M., Medina, J., & De Zutter, L. (2019). Occurrence, genotypes and antimicrobial susceptibility of *Salmonella* collected from the broiler production chain within an integrated poultry company. *Int J Food Microbiol*, *299*:1–7.

Wang, C., Nie, T., Lin, F., Connerton, I.F., Lu, Z., Zhou, S., & Hang, H. (2019). Resistance mechanisms adopted by a *Salmonella* Typhimurium mutant against bacteriophage. *Virus Research, 273*, 197759.

Wernicki, A., Nowaczek, A., & Urban-Chmiel, R. (2017). Bacteriophage therapy to combat bacterial infections in poultry. *Virology journal*, *14*(1), 179.

Wessels, K., Rip, D., & Gouws, P. (2021). *Salmonella* in chicken meat: Consumption, outbreaks, characteristics, current control methods and the potential of bacteriophage use. *Foods, 10*, 1742.

WHO. (2021). Stop using antibiotics in healthy animals to prevent the spread of antibiotic resistance. Retrieved October 21, 2021, from https://www.who.int/news/item/07-11-2017-stop-using-antibiotics-in-healthy-animals-to-prevent-the-spread-of-antibiotic-resistance

Xu, X., Biswas, S., Gu, G., Elbediwi, M., Li, Y., and Yue, M. (2020). Characterization of multidrug resistance patterns of emerging *Salmonella enterica* serovar Rissen along the food chain in China. *Antibiotics (Basel)*, *9*(10):660.

Żbikowska, K., Michalczuk, M., & Dolka, B. (2020). The use of bacteriophages in the poultry industry. *Animals*, *10*(5), 872.

Tables (Chapter 3)

Table 1. Some examples of *Salmonella* bacteriophages applications in the poultry industry

Antimicrobial	Application substrate	Application technique	Location	Reference
Salmonella phage suspension	Chicken skin	Spray	UK	Goode, Allen & Barrow (2003)
Pool of three *Salmonella* bacteriophages (isolated from faeces of free-range chickens)	Chicken cuts	Bacteriophages suspended in one liter of buffer were put in contact with chicken parts	Brazil	Fiorentin, Vieira & Barioni Júnior (2005)
Salmonella phage cocktail (3 lytic phages)	10-day old chicks	By coarse spray or drinking water	Valparaíso, Chile	Borie *et al*., (2008)
SalmoFREE® Sciphage (6 lytic phages; for therapy and control *Salmonella*)	Poultry farm	Delivered to the animals via the drinking water	Bogotá, Colombia	Clavijo *et al*. (2019)
Phage cocktails (4 phages)	Broilers, 20-35 days old	Orally, with drinking water	Santo Domingo de los Tsáchilas, Ecuador	Coba (2020)
Salmonella phage SM1	Poultry litter	Dripping of the phage solution	Brazil	Rogovsky *et al*. (2021)
Bacteriophage solution (*Salmonella* specific)	Feathers of live poultry preslaughter	Spray or fine mist application, or wash	NA	Wessels *et al*. (2021)

NA: Data not available.

Table 2. Origin and number of the isolated *Salmonella* phage mixtures

Phage mixture	**Host bacterium origin**		
Source	**Raw retail chicken meat**	**Poultry farms**	***S*. Typhimurium ATCC 14028**
Machángara River	2^{I}	10^{I}	1
San Pedro River	2^{I}	0	0
Chicken bedding	0	0	2
Chicken slaughter plant water	0	0	4
Chicken house washing water	0	0	1
Chicken cutting machine washing water	0	$6^{I,B,S}$	0
Chicken marinating machine washing water	0	$6^{I,B,S}$	0

Superscripts correspond to the initial of the host *Salmonella* serovar: *I*, Infantis; *B*, Braenderup; *S*, Saintpaul.

Table 3. Antimicrobial resistance patterns of *Salmonella* isolates

Isolate number	*Salmonella* serovar	SXT	CTX	TE	AZM	CIP	AM	GM	C	NA	CRO	AMC	S
1	Braenderup	S	S	S	S	I	S	S	S	S	S	S	S
2	Braenderup	S	S	S	S	S	S	S	S	S	S	S	S
3	*Salmonella* sp.	S	S	S	S	S	S	S	S	S	S	S	S
4	*Salmonella* sp.	S	R	R	S	I	R	S	S	R	R	S	I
5	Infantis	S	R	R	S	I	R	S	S	R	R	S	I
6	*Salmonella* sp.	S	R	R	S	I	R	S	S	R	R	S	I
7	Infantis	S	R	R	S	I	R	S	R	R	R	S	S
8	Infantis	S	R	R	S	S	R	S	S	R	R	R	I
9	Saintpaul	S	S	S	S	S	S	S	S	S	S	S	S
10	Infantis	S	R	R	S	I	R	S	S	R	R	S	R
11	Infantis	R	R	R	S	I	R	I	S	R	R	S	I
12	Infantis	R	R	R	S	I	R	I	S	R	R	S	R
13	Infantis	R	R	R	S	I	R	I	R	R	R	S	I
14	Infantis	S	R	R	S	I	R	S	S	R	R	S	I
15	Infantis	S	R	R	S	I	R	S	S	R	R	S	R
16	Infantis	S	R	R	S	I	R	S	S	R	R	S	R
17	Infantis	S	R	R	S	I	R	S	S	R	R	S	I
18	Infantis	R	R	R	S	I	R	I	S	R	R	S	R
19	Infantis	R	R	R	S	I	R	I	R	R	R	S	R
20	Infantis	R	R	R	S	I	R	I	R	R	R	S	I
21	Infantis	S	R	R	S	I	R	S	S	R	R	S	R
22	Amsterdam	S	S	S	S	I	S	S	S	S	S	S	S
23	Infantis	S	S	S	S	S	S	S	S	S	S	S	S
24	Infantis	R	R	R	S	I	R	I	R	R	R	S	R
25	Infantis	S	R	R	S	I	R	I	R	R	R	S	R
26	Infantis	S	R	R	S	I	R	S	S	R	R	S	R
27	Infantis	S	R	R	S	S	R	S	S	R	R	R	R
28	Infantis	S	R	R	R	I	R	S	I	R	R	S	R
29	Albany	S	S	S	S	S	S	S	S	S	S	S	I
30	Brandenburg	R	R	R	S	I	R	I	R	R	R	S	R
31	Dublin	R	R	R	S	I	R	S	S	R	R	S	R
32	Heidelberg	R	R	R	S	I	R	I	R	R	R	S	R
33	Infantis	S	R	R	S	I	R	S	S	R	R	S	na
34	Infantis	R	R	R	S	I	R	I	R	R	R	S	na

35	Infantis	R	R	R	S	I	R	I	R	R	R	S	na
36	Stanley	R	R	R	R	I	R	I	R	R	R	S	I
37	Typhimurium	S	S	S	R	I	R	S	S	S	S	R	na
38	Infantis	R	R	R	S	I	R	I	R	R	R	S	na

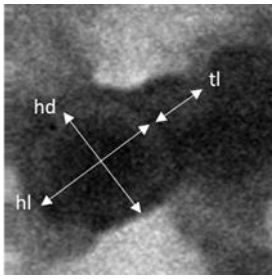
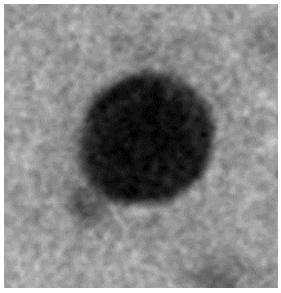
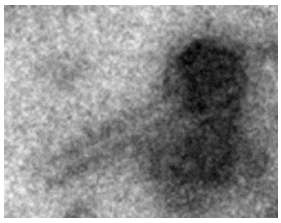
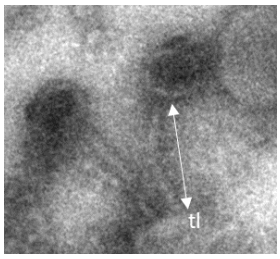
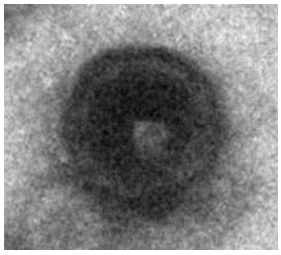
Abbreviations: I, intermediate; R, resistant; S, susceptible; na, data not available; AM, ampicillin; AMC, amoxicillin-clavulanic acid or amoxicillin-clavulanate; AZM, azithromycin; C, chloramphenicol; CIP, ciprofloxacin; CTX, cefotaxime; CRO, ceftriaxone; GM, gentamicin; NA, nalidixic acid; TE, tetracycline; S, streptomycin; SXT, sulphamethoxazole-trimethoprim (CLSI, 2021). The trial was performed once (n = 1).

Table 4. Characteristics of the phage-resistant *Salmonella* isolates.

***Salmonella* isolate number**	**Serovar**	**Origin**	**Antimicrobial resistance pattern**
8	Infantis	Chicken bedding	CTX, TE, AM, NA, CRO, AMC, S(I)
26	Infantis	Chicken bedding	CTX, TE, AM, NA CRO, S
27	Infantis	Chicken bedding	CTX, TE, AM, NA, CRO, AMC, S
22	Amsterdam	Animal feed	CIP(I)
29	Albany	Chicken bedding	S(I)
31	Brandenburg	Raw retail chicken meat	SXT, CTX, TE, AM, C, NA, CRO, S, CIP(I), GM(I)
38	Typhimurium	Raw retail chicken meat	AZM, AM, AMC, CIP(I)

Abbreviations: I, intermediate resistance; AM, ampicillin; AMC, amoxicillin-clavulanic acid or amoxicillin-clavulanate; AZM, azithromycin; C, chloramphenicol; CIP, ciprofloxacin; CTX, cefotaxime; CRO, ceftriaxone; GM, gentamicin; NA, nalidixic acid; TE, tetracycline; S, streptomycin; SXT, sulphamethoxazole-trimethoprim (CLSI, 2021).

Table 5. Classification of the phages observed in photomicrographs.

Phage name	Phage family (hl, hd, tl, td) (nm)	Electron photomicrograph
Salmonella phage M061_16_1	*Podoviridae* (102, 98, 39, 45)	
Salmonella phage M061_16_2	*Podoviridae* (82, 72, 20, 18)	
Salmonella phage M061_17_1	*Siphoviridae* (66, 65, 148, 9)	
Salmonella phage M061_17_2	*Siphoviridae* (55, 68, 140, 13)	
Salmonella phage M061_17_3	*Podoviridae* (118, 119, 22, 33)	

Supplementary Material (Chapter 3)

Table S1. Data from phage source samples

Sample type	Origin (location)	Sample number/quantity	Sampling date
Wastewater	Machángara river (Quito, Ecuador)	1 sample (ca 1 US gal)	February 2019
Wastewater	San Pedro river (Quito, Ecuador)	1 sample (ca 1 US gal)	February 2019
Chicken bedding samples	Poultry farms (Pichincha Province, Ecuador)	6 samples from 6 chicken houses (two composite samples were made, each one with samples from 3 houses)	May 2019
Washing water	Poultry slaughter plant (Pichincha Province, Ecuador)	8 samples: Pre-chiller (1, chicken), chiller (2, chicken and turkey), scalder (2, chicken and turkey), gutting machines (2, chicken), and final poultry washing (1, turkey)	June 2019
Washing water	Poultry processing plant (Quito, Ecuador)	2 samples: Poultry cutting and marinating machines	August 2019

CHAPTER 4

General discussion

From the results of the systematic review on nontyphoidal *Salmonella* (NTS) in foods from Latin America, there are two food groups in which the presence of this pathogen is particularly alarming, and it is urgent to combat it: Meat products, and fresh fruits and vegetables.

Meat products, for two reasons: (1) The highest prevalence of NTS (> 70%) were found in these foods, and (2) the high incidence of multidrug-resistant (MDR) isolates, since 90% of the reports of antimicrobial resistance (AMR) were related to meats and derived products. NTS contaminates meat because healthy animals can carry this pathogen and their carcasses become contaminated with gastrointestinal content during slaughter (Gómez-Aldapa *et al*., 2012; Contreras-Soto *et al*., 2019), while the high AMR rate reflects the selective pressure exerted on bacteria by the misuse of antimicrobials in animal husbandry (Silva, Calva & Maloy, 2014; McDermott, Zhao & Tate, 2018). AMR in animal foods should constitute an urgent call for attention to an increasing worldwide problem: the spread of MDR isolates through food and its contribution to the global problem of AMR (Mejía, Vela & Zapata, 2020; Vidovic & Vidovic, 2020; CDC, 2021). To achieve a reduction of antimicrobial use in food production, the participation of governmental and non-governmental organizations in charge for the control and training of producers is required. It is also necessary the commitment of the producers of foods of animal origin (including farmers, poultry farmers, fish farmers, etc.) to reduce antimicrobial use in their activities. Finally, the involvement of academia would be desirable, sharing knowledge with the productive sectors, and contributing with accessible solutions (de Freitas *et al*., 2010; Vidovic & Vidovic, 2020).

Fresh fruits and vegetables are increasingly implicated in salmonellosis outbreaks and are considered an important route of entry of NTS in the food chain. Furthermore, MDR bacterial strains have also been reported in these foods (Cordano and Virgilio, 1996; Almeida *et al*., 2018; Montero *et al*., 2021).

If *Salmonella* was originally adapted to the microenvironment of the animals' gastrointestinal tract, what are the pathways and mechanisms for this bacterium to be so successful in vegetables? There are numerous studies that contribute on answering this question.

Once *Salmonella* leaves the animal gastrointestinal tract, it can survive and even multiply in faecal matter, allowing it to increase its population and the chances of reaching other hosts (Guerrero *et al*., 2020). In low- and middle-income countries, manure is used as fertilizer without adequate treatment, constituting a potential source of *Salmonella* for produce (Gallegos-Robles *et al*., 2008; Fletcher *et al*., 2013). Through its dispersion in the environment, this pathogen can also reach surface waters that, in addition to protecting it from solar UV radiation and changes in pH and temperature, are often used for irrigation and are the vehicle for this pathogen to reach crops (Liu, Whitehouse & Li, 2018).

The surface of some rough fruits and vegetables provides a niche for *Salmonella* and if their population is large enough, consumption of the agricultural product can cause human disease. On the other hand, this pathogen can also enter the leaves through structures such as trichomes and stomata, and benefit from nutrients resulting from the degradation of plant tissues by phytopathogenic bacteria that thus promote the growth of *Salmonella* in the plant and its colonization, and the vegetable becomes an alternative host (Liu *et al*., 2018). Hence the importance of preventing the pathogen from reaching crops, because if it penetrates plant tissues, subsequent disinfection treatments could be ineffective (da Cruz *et al*., 2019).

To effectively prevent contamination of crops with *Salmonella* it is important to know its physiology outside of an animal host. For this purpose, we carried out a series of experiments

to determine if this pathogen can replicate in faecal matter outside a host. Our results showed that *Salmonella* multiplies massively and through aerobic respiration in chicken fresh faecal matter, which agrees with the findings of Litvak and colleagues (2019), who found that *Salmonella* Enteritidis requires an increase in epithelial oxygenation in the chicken's intestine for expansion by aerobic respiration (Litvak *et al*., 2019). We also found that the growth of NTS increases when that of *E. coli* decreases, suggesting a possible antagonism between these two bacteria, which could be due to competition for oxygen. Similarly, the results of Litvak (2019) suggest that *S*. Enteritidis competes with commensal *Enterobacteriaceae* for oxygen (Litvak *et al*., 2019).

Our results showed critical implications in procedures related to food production: (1) It is essential to treat manure to eliminate *Salmonella* and other pathogens before using it as fertilizer; composting (Singh, Kim, & Jiang, 2012; Román, Martínez, & Pantoja, 2015) or procedures that generate anaerobic conditions, as anaerobic lagoons and digesters (Spiehs & Goyal, 2007) can be used for this purpose. (2) When there are faeces residues, *Salmonella* can multiply in chicken bedding and spread among poultry. The bedding material is often used raw or after improper composting, as fertilizer (Chen & Jiang, 2014), producing food crops contamination. Bodi and colleagues (2013) found that the aeration by tumbling of the chicken litter can increase the multiplication and dissemination of *Salmonella* when there is high poultry population density, improper ventilation of the facilities, or the presence of humidity and excrement of *Salmonella* (Bodi *et al*., 2013). These findings are consistent with our conclusions that the presence of oxygen favors the multiplication of *Salmonella* in the presence of faecal matter (Guerrero *et al*., 2020). For this reason, it is necessary to look for cleaning and disinfection procedures that do not create favorable conditions for its growth.

NTS is the leading bacterial cause of foodborne illness worldwide (CDC, 2020). Although most cases of salmonellosis in humans are mild, foodborne illness causes economic losses for

governments, producers, and consumers (FAO, 2020). To control this pathogen in food animals' production, bacteriophages (phages) are a viable option, considering the current restrictions on the use of antimicrobials in animal husbandry. Phage safety, compared to antimicrobials, is due to its specificity of host bacteria, since in general, each type of phage has the capacity to infect only one species, serotype or strain, and does not affect the commensal microbiota (Hagens, & Loessner, 2010; Wernicki, Nowaczek, & Urban-Chmiel, 2017).

There are pros and cons of using phages as antibacterials in the food industry (Hagens, & Loessner, 2010; Loc-Carrillo, & Abedon, 2011), as presented below (Fig. 1).

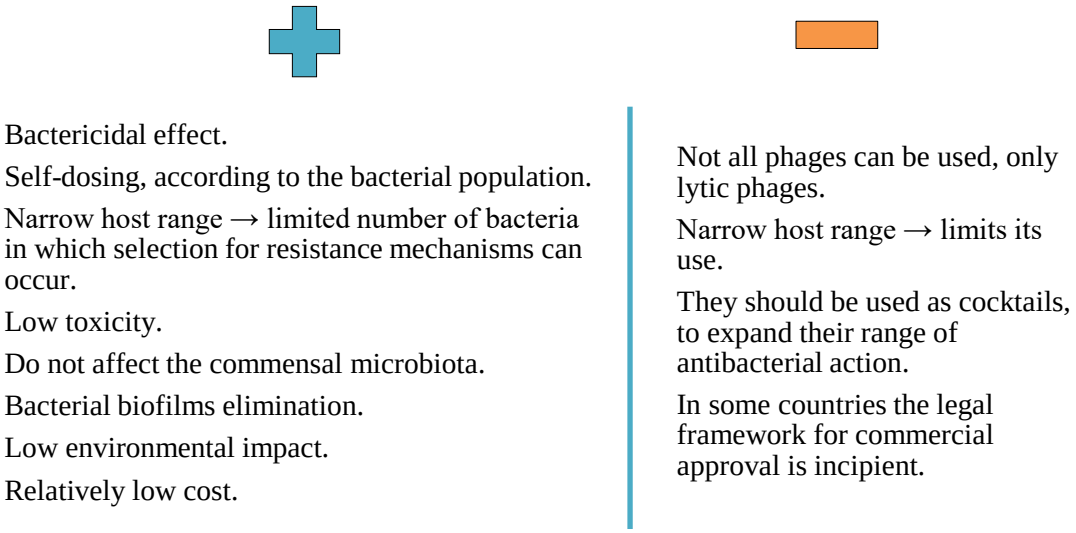


Figure 1. Summary of pros and cons of phages as antimicrobials in the food industry previously stated by Hagens & Loessner (2010), and Loc-Carrillo & Abedon (2011).

In several countries phages are being used in the food animals' husbandry and applied on the surface of foods of animal and vegetable origin, to eliminate pathogens (Wernicki *et al*., 2017). Despite their safety, it is recommended that the phages for use food have the following properties: (1) "Wide" host range, that is, they infect some members of the species or genus to be eliminated; (2) be lytic (virulent); (3) can be propagated in a non-pathogenic host; (4) known complete genome to ensure absence of pathogenicity genes; (5) stable during storage and application; (6) not cause adverse effects when administered orally; and (7) GRAS approval for

use in food (Hagens & Loessner, 2010). In the present work, some of the requirements were verified to apply *Salmonella* phages on-farm, others are in process. The verified requirements are: 1) The use of lytic phages for on-farm application; 2) phages were propagated in *Salmonella* isolates from raw chicken meat, but prior to application, phage suspensions were filtered to remove bacterial contamination; 3) it was confirmed that phages were not toxic to chickens. The genomic characterization of our phages is in progress, and we need to do stability tests during their storage and application.

A widespread application of phages in food production could also have negative consequences if control measures are not taken. These consequences could be the uncontrolled spread of phages, and the persistence and dispersal of bacterial isolates resistant to them (Sommer *et al*., 2019); it has been seen that with prolonged treatments the appearance of isolates resistant to phages is more likely (Carvalho *et al*., 2010). In our on-farm applications, the longest period between oral phage administration and chickens slaughter was 10 days; thus, our intervention would not be a risk factor for the proliferation of phage-resistant isolates. Regarding the application in chicken bedding, it is necessary to develop a cleaning and disinfection plan that eliminates *Salmonella* and, consequently, phages, and periodically verify its compliance and effectiveness.

We had longer poultry protection against *Salmonella* by combining oral phage administration and spraying, however, we did not compare the effectiveness of these two routes separately. Borie and colleagues (2008) compared these two application routes and obtained better results using spraying (phages isolated from sewage samples) (Borie *et al*., 2008). On the other hand, unlike Clavijo and colleagues (2019), who eliminated 100% of *Salmonella* in poultry using a commercial phage cocktail orally in multiple doses (a weekly dose for three weeks) (Clavijo *et al*., 2019), we controlled *Salmonella* with a single application combining via oral and spraying.

In summary, proper waste treatment is critical to avoid contamination of crops with pathogens such as NTS. In food animals' husbandry, phage application is a viable option for the control of this pathogen, instead of antimicrobials. It is important to reduce the on-farm incidence of NTS because it diminishes its detection in slaughterhouses and, consequently, in food, which protects consumers from disease.

References

Almeida, F., Seribelli, A.A., Medeiros, M.I., Rodrigues, D., Mello Varani A. de, Luo, Y., Allard, M.W., & Falcao, J. (2018). Phylogenetic and antimicrobial resistance gene analysis of *Salmonella* Typhimurium strains isolated in Brazil by whole genome sequencing. *PloS One, 13*(8):1-16.

Bodi, S.G., Garcia, A.V., Garcia, S.V., & Orenga, C.M. (2013). Litter aeration and spread of *Salmonella* in broilers. *Poultry science, 92*(8), 2005–2011.

Borie, C., Albala, I., Sánchez, P., Sánchez, M.L., Ramírez, S., Navarro, C., Morales, M.A., Retamales, A.J., & Robeson, J. (2008). Bacteriophage treatment reduces *Salmonella* colonization of infected chickens. *Avian diseases, 52*(1), 64–67.

Carvalho, C.M., Gannon, B.W., Halfhide, D.E., Santos, S.B., Hayes, C.M., Roe, J.M., & Azured, J. (2010). The *in vivo* efficacy of two administration routes of a phage cocktail to reduce numbers of *Campylobacter coli* and *Campylobacter jejuni* in chickens. *BMC Microbiol, 10*, 232.

CDC. (2020). Foodborne Germs and Illnesses. Retrieved August 27, 2020, from https://www.cdc.gov/foodsafety/foodborne-germs.html

CDC. (2021). Food and food animals. Retrieved October 22, 2021, from https://www.cdc.gov/drugresistance/food.html

Chen, Z., & Jiang, X. (2014). Microbiological safety of chicken litter or chicken litter-based organic fertilizers: A review. *Agriculture*, *4*(1), 1–29.

Clavijo, V., Baquero, D., Hernandez, S., Farfan, J.C., Arias, J., Arévalo, A., Donado-Godoy, P., & Vives-Flores, M. (2019). Phage cocktail SalmoFREE® reduces *Salmonella* on a commercial broiler farm. *Poultry science*, *98*(10), 5054–5063.

Contreras-Soto, M.B., Medrano-Félix, J.A., Ibarra-Rodríguez, J.R., Martínez-Urtaza, J., Chaidez, Q.C., & Castro-del Campo, N. (2019). The last 50 years of *Salmonella* in Mexico: Sources of isolation and factors that influence its prevalence and diversity. *Revista Bio Ciencias, 6*:1–26.

Cordano, A.M., & Virgilio, R. (1996). Evolution of drug resistance in *Salmonella* Panama

isolates in Chile. *Antimicrob Agents Chemother*, *40*(2):336-341.

da Cruz, M., Leite, Y.J., Marques, J., Pavelquesi, S.L., Oliveira, L., da Silva, I.C., & Orsi, D. (2019). Microbiological quality of minimally processed vegetables commercialized in Brasilia, DF, Brazil. *Food Sci Technol, 39*:1–6.

de Freitas, O.C., Penha, R.A., Barrow, P., & Berchieri, A. (2010). Sources of human non-typhoid salmonellosis: A review. *R Bras Ci Avíc, 12*:1–11.

FAO. (2020). Food safety and animal and plant health in Latin America and the Caribbean | FAO Regional Office for Latin America and the Caribbean | Food and Agriculture Organization of the United Nations. Retrieved August 27, 2020, from http://www.fao.org/americas/prioridades/sanidad-inocuidad-agroalimentaria/en/

Fletcher, J., Leach, J.E., Eversole, K., & Tauxe, R. (2013). Human pathogens on plants: designing a multidisciplinary strategy for research. *Phytopathology Perspectives*, *103*:306–315.

Gallegos-Robles. M.A., Morales-Loredo, A., Alvarez-Ojeda, G., Vega-P, A., Chew-M, Y., Velarde, S., & Fratamico, P. (2008). Identification of *Salmonella* serotypes isolated from cantaloupe and chile pepper production systems in Mexico by PCR-restriction fragment length polymorphism. *J Food Prot*, *71*:2217–2222.

Gómez-Aldapa, C.A., Torres-Vitela, M.R., Villarruel-López, A., & Castro-Rosas, J. (2012). The role of foods in *Salmonella* infections. In: *Salmonella - A Dangerous Foodborne Pathogen*. Mahmoud BS, ed. Croatia: InTech, pp. 21–46.

Guerrero, T., Calderón, D., Zapata, S., & Trueba G. (2020). *Salmonella* grows massively and aerobically in chicken faecal matter. *Microb Biotechnol*, *13*:1678–1684.

Hagens, S., & Loessner, M.J. (2010). Bacteriophage for biocontrol of foodborne pathogens: calculations and considerations. *Curr Pharm Biotechnol*, *11*(1):58-68.

Litvak, Y., Mon, K., Nguyen, H., Chanthavixay, G., Liou, M., Velazquez, E.M., Kutter, L., Alcantara, M.A., Byndloss, M.X., Tiffany, C.R., Walker, G.T., Faber, F., Zhu, Y., Bronner, D.N., Byndloss, A.J., Tsolis, R.M., Zhou, H., and Bäumler, A.J. (2019). Commensal *Enterobacteriaceae* protect against *Salmonella* colonization through oxygen competition. *Cell host and microbe*, *25*(1), 128–139.

Liu, H., Whitehouse, C.A., & Li, B. (2018). Presence and persistence of *Salmonella* in water: The impact on microbial quality of water and food safety. *Front Public Health, 6*:159.

Loc-Carrillo, C., & Abedon, S.T. (2011). Pros and cons of phage therapy. *Bacteriophage, 1*(2), 111–114.

McDermott, P.F., Zhao, S., & Tate, H. (2018). Antimicrobial resistance in nontyphoidal *Salmonella*. *Microbiology spectrum*, *6*(4).

Mejia, L., Vela, G., & Zapata, S. (2020). High occurrence of multiresistant *Salmonella* Infantis in retail meat in Ecuador. *Foodborne pathogens and disease*, *18*(1), 41–48.

Montero, L., Irazabal, J., Cardenas, P., Graham, J.P., & Trueba, G. (2021). Extended-spectrum Beta-lactamase producing-*Escherichia coli* isolated from irrigation waters and produce in Ecuador. *Front. Microbiol*. *12*:709418.

Román, P., Martínez, M.M., & Pantoja, A. (2015) Chapter 3. Theoretical foundations of composting. In *Farmer's Compost Handbook. Experiences in Latin America*. Santiago, Chile: Food and Agriculture Organization of the United Nations Regional Office for Latin America and the Caribbean, pp. 11–21. http://www.fao.org/3/a-i3388e.pdf.

Silva, C., Calva, E., & Maloy, S. (2014). One Health and food-borne disease: *Salmonella* transmission between humans, animals, and plants. *Microbiol Spectr, 1*:1–9.

Singh, R., Kim, J., & Jiang, X. (2012) Heat inactivation of *Salmonella* spp. in fresh poultry compost by simulating early phase of composting process. *J Appl Microbiol*, *112*:927–935.

Sommer, J., Trautner, C., Witte, A.K., Fister, S., Schoder, D., Rossmanith, P., & Mester, P.J. (2019). Don't shut the stable door after the phage has bolted-The importance of bacteriophage inactivation in food environments. *Viruses*, *11*(5), 468.

Spiehs, M., & Goyal, S. (2007). *Best management practices for pathogen control in manure management systems*. Report, University of Minnesota Extension. Retrieved October, 22, 2021, from http://lshs.tamu.edu/docs/lshs/end-notes/bmps%20for%20pathogen%20control%20in%20manure%20management%20systems-1916131611/bmps%20for%20pathogen%20control%20in%20manure%20management%20systems.pdf

Vidovic, N., & Vidovic, S. (2020). Antimicrobial resistance and food animals: Influence of livestock environment on the emergence and dissemination of antimicrobial resistance. *Antibiotics (Basel), 9*(2):52.

Wernicki, A., Nowaczek, A., & Urban-Chmiel, R. (2017). Bacteriophage therapy to combat bacterial infections in poultry. *Virology journal*, *14*(1), 179.

FINAL REMARKS

Conclusions

The importance of nontyphoidal *Salmonella* (NTS) in food production and the difficulty of its control in the poultry industry is well known; the main factor for NTS entering the food chain is its presence on farms (Pelyuntha *et al*., 2021). In Latin America, animal foods showed the highest prevalence of NTS, and multidrug-resistant (MDR) isolates have been reported with more frequency in this food. In Ecuador, NTS is present in 88% of chicken carcasses, and 91% of strains are MDR (Vinueza-Burgos *et al*., 2019).

Once excreted, *Salmonella* multiplies massively in chicken faecal matter, which constitutes its intermediate habitat (Barrera *et al*., 2018). This behavior appears to increase the chances for NTS to reach new hosts. Based on this knowledge, effective measures can be taken to prevent this pathogen from contaminating food sources.

With the alarming increase in bacterial resistant to antimicrobials and the consequent regulation in their use, bacteriophages (phages) constitute an alternative for pathogens control. We were successful in eliminating *Salmonella* by applying on-farm lytic phages isolated from the Machángara river (Quito). The best method was the combination of oral administration to chickens with drinking water and spraying on chicken bedding for three days. Our conclusion is that phages are a viable alternative, due to their safety and relatively low cost, to control *Salmonella* in poultry production. The emergence of phage-resistant *Salmonella* strains should be constantly monitored to seek new phages that eliminate them, and to implement strict disinfection protocols in all facilities. In addition, as its use spreads, processes should be implemented that allow the production of phages to be scaled up to levels higher than in the laboratory, which was how this research was carried out.

Recommendations

Systematic review

It is recommendable to limit the bibliographic search to a topic as specific as possible. The narrower the range of knowledge covered, the deeper the information can be and the more applicable the results.

Experiments on the multiplication of Salmonella in chicken faecal matter

(1) It would be interesting to test whether NTS has the same behavior in the faecal matter of other animals that are reservoirs of different *Salmonella* serovars.

(2) A complement to our work would be to determine the metabolic pathways used by the pathogen in these experiments, using mutant strains for the pathways under study (Litvak *et al*., 2019).

Bacteriophages for the control of Salmonella in poultry

(1) To compare the efficacy of administering phages with drinking water and with food. Food has been found to protect phages from being inactivated by low pH throughout the poultry digestive tract (Carvalho *et al*., 2010).

(2) In addition to performing the qualitative *Salmonella* detection to evaluate the phage efficacy, quantify their population before and after the phage application, to compare different treatments and concentrations (Xie *et al*., 2021).

(3) To confirm that phages cannot perform a lysogenic cycle, to ensure that they are exclusively lytic (Hagens & Loessner, 2010).

(4) To combine two or more antibacterial agents against *Salmonella* (phages, probiotics, feed acidification) in the administration to chickens, to determine if there is a synergistic effect (Clavijo & Vives, 2017).

Future perspectives

The present research has future perspectives, as it is the beginning of a project that continues to be developed, based on the application of *Salmonella* phages on-farm. Through electron microscopy, the characterization of the individual phages began but there are further steps to pursue; the next step will be genomic characterization. Additionally, phages that kill resistant *Salmonella* strains (Table 6, Chapter 3) will be isolated from new environmental samples.

In the short term, it would be desirable to define all conditions of phage on-farm application in various poultry farms (related to the farm where the application was carried out).

In the medium and long term, the expectation is to totally replace the use of antibiotics in the poultry industry in Ecuador, and phages could be part of the strategy to achieve this ambitious goal.

Limitations

The main limitation was not having experimental units (groups of chickens that receive different treatment) to test the phage effectiveness, so the respective controls were not available and the necessary repetitions for a statistical analysis of the data could not be carried out.

References

Carvalho, C.M., Gannon, B.W., Halfhide, D.E., Santos, S.B., Hayes, C.M., Roe, J.M., & Azured, J. (2010). The *in vivo* efficacy of two administration routes of a phage cocktail to reduce numbers of *Campylobacter coli* and *Campylobacter jejuni* in chickens. *BMC Microbiol 10*, 232.

Clavijo, V., & Flórez, M.J.V. (2017). The gastrointestinal microbiome and its association with the control of pathogens in broiler chicken production: A review. *Poultry Science, 97*(3), 1006–1021.

Hagens, S., & Loessner, M.J. (2010). Bacteriophage for biocontrol of foodborne pathogens: calculations and considerations. *Curr Pharm Biotechnol, 11*(1):58-68.

Litvak, Y., Mon, K.K.Z., Nguyen, H., Chanthavixay, G., Liou, M., Velazquez, E.M., Kutter, L., Alcantara M.A., Byndloss, M.X., Tiffany, C.R., Walker, G.T., Faber, F., Zhu, Y., Bronner, D.N., Byndloss, A.J., Tsolis, R.M., Zhou, H., & Bäumler, A.J. (2019).

Commensal *Enterobacteriaceae* protect against *Salmonella* colonization through oxygen competition. *Cell Host Microbe, 25*(1):128-139.

Pelyuntha, W., Ngasaman, R., Yingkajorn, M., Chukiatsiri, K., Benjakul. S., & Vongkamjan, K. (2021). Isolation and characterization of potential *Salmonella* phages targeting multidrug-resistant and major serovars of *Salmonella* derived from broiler production chain in Thailand. *Front Microbiol, 12*:662461.

Vinueza-Burgos, C., Baquero, M., Medina, J., & De Zutter, L. (2019). Occurrence, genotypes and antimicrobial susceptibility of *Salmonella* collected from the broiler production chain within an integrated poultry company. *Int J Food Microbiol, 299*:1–7.

Xie, Y., Thompson, T., O'Leary, C., Crosby, S., Nguyen, Q.X., Liu, M., & Gill, J.J. (2021). Differential bacteriophage efficacy in controlling *Salmonella* in cattle hide and soil models. *Front Microbiol, 12*:657524.

INDICE DE ANEXOS

Supplementary Material Chapter 1

Supplementary Material Chapter 2

Supplementary Material Chapter 3

Curriculum Vitae Esthela Teresa Guerrero Villegas

Educación

Inicio del PhD en Microbiología, USFQ, enero del 2017.

Maestría en Seguridad y Prevención de Riesgos del Trabajo, Universidad Tecnológica Equinoccial, Quito, 2015.

Bioquímica Farmacéutica. Opción Bioquímica de Alimentos, Universidad Central del Ecuador, Quito, 1994.

Publicaciones

Guerrero T., Bayas-Rea, R., Erazo, E., Zapata Mena, S. (2021). Systematic Review: Nontyphoidal *Salmonella* in Food from Latin America. *Foodborne pathogens and disease*, 10.1089/fpd.2020.2925. Advance online publication.

Guerrero T., Calderón D., Zapata S., Trueba G. (2020). *Salmonella* grows massively and aerobically in chicken faecal matter. *Microb Biotechnol*, *13*:1678–1684.

Jijón M.J., Guerrero Villegas T., Barahona A., Aguilar Barriga, P. (2017). The visual effect and the necessity of determinating the superficial whitening method of the macadamia's nut. *Enfoque UTE*, *8*(5), pp. 46 - 52.

Guerrero Villegas T., Mora Flores G. (2014). Possible health risks due to the consumption of aspartame. *Enfoque UTE*, *5*(2), pp. 1 - 13.

Trueba G., Guerrero T., Fornasini M., Casariego I., Zapata S., Ontaneda S., Vasco L. (2000). Detection of *Fasciola hepatica* infection in a community located in the Ecuadorian Andes. *Am. J. Trop. Med. Hyg.*, *62*(4), 2000, p. 518.

Presentaciones orales, pósters y curso (durante el doctorado)

Second ISME Latin American Congress 2021. Julio 27-30, 2021. Asistencia y presentación de poster: The use of bacteriophages to control *Salmonella* in poultry operations.

Exposición oral 2º Congreso de Ciencias Biológicas y Ambientales USFQ. Noviembre 29, 2019. Título: Una manera diferente de combatir *Salmonella* en aves de corral. https://revistas.usfq.edu.ec/index.php/archivosacademicos/article/view/1637/1823

Póster en el I Congreso Internacional de Biotecnología UDLA. Octubre 16-18, 2019. Título: Bacteriófagos como alternativa al uso de antibióticos en la crianza de aves de corral. www.researchgate.net/publication/338439339_Bacteriophages_as_an_alternative_to_the_use_of_antibiotics_in_poultry_breeding

Exposición en Coloquio “Microbiología y sus diversas aplicaciones” ASM-PUCE. Agosto 30, 2019. Título: Bacteriófagos como alternativa al uso de antibióticos en la crianza de aves de corral.

Curso: Los Bacteriófagos: del Genoma al Metagenoma. Universidad de Buenos Aires. Marzo 6-19, 2019; 80 horas.

Experiencia profesional

Universidad Tecnológica Equinoccial. Profesor Auxiliar. Septiembre 2009 - enero 2016.

Universidad Internacional SEK Ecuador. Profesor Auxiliar. Octubre 2007 - septiembre 2009.

Universidad San Francisco de Quito. Laboratorio de Microbiología. Agosto 1996 - agosto 1997; agosto 1998 - febrero 2000.

Merck Sharp & Dohme Ecuador. Laboratorio de Microbiología. Mayo - agosto, 1996.

Universidad Central del Ecuador. Facultad de Ciencias Químicas, Laboratorio de Microbiología. Febrero 1994 - enero 1996.