Antimicrobial resistance and related gene analysis of *Salmonella* from egg and chicken sources by whole-genome sequencing

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**ABSTRACT** Whole-genome sequencing (WGS) is a valuable tool in research on foodborne pathogens. In this study, a total of 143 isolates of *Salmonella* serotypes Enteritidis, Typhimurium, and Heidelberg sourced from eggs and chickens were analyzed for their antimicrobial resistance profiles using WGS data. The isolates carried high rate of genes resistant to aminoglycoside (70.63%), tetracycline (26.57%), fosfomycin (25.17%), sulfonamides (23.78%), and β-lactamases (15.38%); and *aadA* was the most frequently observed antimicrobial resistance gene (ARG). Antimicrobial resistance varies by *Salmonella* serotypes, with *Salmonella enterica* serovar Enteritidis (*Salmonella* ser. Enteritidis) isolates being highly resistant to aminoglycoside (particularly streptomycin); *Salmonella* ser. Typhimurium more resistant to aminoglycoside, tetracycline, and sulfonamides; and *Salmonella* ser. Heidelberg more resistant to aminoglycoside and fosfomycin. *Salmonella* ser. Typhimurium isolates presented more varieties of ARG than *Salmonella* ser. Enteritidis and *Salmonella* ser. Heidelberg. Our data showed that 5 isolates of *Salmonella* ser. Typhimurium and *Salmonella* ser. Heidelberg contained ARG resistant to ≥ 5 antimicrobials. In addition, 23 *Salmonella* isolates carried ARG resistant to 4 antimicrobials.

**Key words:** *Salmonella*, WGS, antimicrobial resistance, egg, chicken

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**INTRODUCTION**

*Salmonella* has always been a serious threat to global public health. In the United States, *Salmonella* caused approximately 1.2 million illnesses and 450 deaths annually; and about 1 million of these illnesses were due to contaminated foods (Centers for Disease Control and Prevention (CDC), 2019; Scallan et al., 2011). It was estimated that *Salmonella* serotypes Enteritidis, Typhimurium, and Heidelberg caused about 50% of the foodborne salmonellosis outbreaks in the United States and were frequently isolated from eggs and egg products, chicken meats, chicken ovaries, and feces (Schoeni et al., 1995; Chittick et al., 2006; Gast et al., 2017).

In the past 20 yr, the increasing resistance to medically important antimicrobial agents in *Salmonella* has been widely reported (Su et al., 2004). The emerging and spreading new resistance mechanisms contributed to the deteriorating situation of antimicrobial resistance and threatened the ability to treat foodborne diseases, then caused more prolonged illnesses, disabilities, and deaths (World Health Organization (WHO), 2018). The Centers for Disease Control and Prevention (CDC) estimated at least 2 million people are infected with antibiotic-resistant bacteria annually in the United States, leading to at least 23,000 deaths (CDC, 2018a). Furthermore, widespread of multidrug-resistance (resistance to more than 4 antibiotic classes) *Salmonella*, particularly *Salmonella* ser. Typhimurium, to the most commonly used antibiotics in human beings, has made it an even greater threat to the public health (CDC, 2014; European Center for Disease Prevention and Control (ECDC), 2009; European Food Safety Authority (EFSA) and ECDC, 2017). During 2009–2011, about 5% of nontyphoidal *Salmonella* tested by the CDC were resistant to ≥5 types of drugs (CDC, 2013). For the 2,364 *Salmonella* isolates from humans, retail meats, and food-producing animals tested in the United States in 2015, 65 of them (2.7%) were resistant.
to at least 5 antimicrobial agents: ampicillin, chloramphenicol, streptomycin, sulfonamide (sulfamethoxazole/sulfisoxazole), and tetracycline. *Salmonella* ser. Typhimurium was the serotype that most frequently presented ampicillin, chloramphenicol, streptomycin, sulfonamide (sulfamethoxazole/sulfisoxazole), and tetracycline resistance with a prevalence of 10.8% (27 of 251) (CDC, 2018b). From 1998 to 2003, the US Food Safety and Inspection Service tested 293,938 samples sourced from meat and poultry products and pasteurized egg products; of which, 136 (91.9%) of the 148 *Salmonella* ser. Enteritidis isolates from these samples were pansusceptible; 12 resistant isolates showed resistance to ampicillin (11), tetracycline (3), sulfamethoxazole (4), cephalothin (3), and ticarcillin (3); and 4 of the 12 isolates were resistant to 4 or more antimicrobials (White et al., 2007). Suresh et al. (2006) tested 492 eggs (492 eggshell and 492 egg content) and 82 egg-storing trays during 1-year period in South India; 40 *Salmonella* ser. Enteritidis isolates from the 46 *Salmonella* positive samples were all determined to be resistant to at least 4 drugs. Among the 46 positive samples, 5.3% was from eggshell, 1.8% from egg contents, and 6.1% from egg storing trays (Suresh et al., 2006). There are many mechanisms of actions that could cause antibiotic resistance, such as inhibiting an enzyme, altering the cell membrane permeability (ionophores), affecting the structure of the cell wall, interfering with DNA/protein synthesis (mutations, horizontal gene transfer) (Barbosa and Levy, 2000; Giedraitiené et al., 2011). Therefore, a collective effort should be made to limit the spread of resistance and reduce the impact of these extremely harmful bacteria.

Whole-genome sequencing (WGS) technology has attracted so much attention in the last decade, owing to its unique power in data generation, evolution and epidemiology study, microbiological risk assessment, and outbreak investigation. Scientists also use WGS to rapidly identify antimicrobial resistance genes (ARG) and gene clusters and mutations of these genetic elements in foodborne pathogens. Based on the WGS data, a novel trimethoprim-resistance gene dfrA34 has been identified in *Salmonella* ser. Heidelberg (Tagg et al., 2018). In a Québec study, 65 of 69 (96.9%) *Salmonella* ser. Heidelberg isolates investigated contained blaCMY-2 plasmids; 2 blaCMY-2 plasmids were found to have been inserted into the chromosome and the CMY-2 plasmid transmission occurred among *Salmonella* ser. Heidelberg isolates with variable genetic backgrounds (Edirmanasinghe et al., 2017).

The National Center for Biotechnology Information Pathogen Detection system is a centralized Web-based portal that integrates the genomic sequence, metadata, antibiotic susceptibility and resistance gene information, and the SNP cluster information, widely used for outbreak investigation, source tracking, and epidemiologic studies of bacterial pathogens, such as *Salmonella*, *Campylobacter*, *Listeria*, *Escherichia coli*, and *Shigella* (https://www.ncbi.nlm.nih.gov/pathogens/).

The objectives of this study were 1) to investigate the prevalence of ARG in 143 isolates of 3 *Salmonella* serotypes (*Salmonella* ser. Enteritidis, *Salmonella* ser. Typhimurium, and *Salmonella* ser. Heidelberg) sourced from eggs and chickens, using WGS data and 2) to compare the differences regarding the occurrence and trends of ARG in these pathogens, highlighting the differences among the 3 serotypes investigated.

### MATERIALS AND METHODS

**Salmonella Isolates**

A total of 143 *Salmonella* isolates from egg and chicken sources, including 64 *Salmonella* ser. Enteritidis collected from 1995 to 2016 (Table 1), 40 *Salmonella* ser. Typhimurium collected from 2001 to 2010 (Table 2), and 39 *Salmonella* ser. Heidelberg collected from 2003 to 2013 (Table 3), were used in this study. All isolates were in the collection of Division of Microbiology, Office of Regulatory Science, Center for Food Safety and Applied Nutrition (CFSAN), U.S. Food and Drug Administration (FDA). These isolates were cultured overnight at 37 ± 2°C in Trypticase Soy Broth (Becton Dickinson, Franklin Lakes, NJ) for DNA extraction.

**Whole-Genome Sequencing**

Isolates were cultured for 16 ± 1 h at 37 ± 2°C in Trypticase Soy Broth. Genomic DNA from each isolate was extracted and purified using the DNeasy Blood and Tissue Kit (Qiagen, Inc., Valencia, CA). Concentrations of DNA were measured using a Qubit 3.0 fluorometer (Life Technologies, MD). Genomic DNA was sequenced on the Illumina MiSeq/NextSeq 500 platform following the manufacturer’s instructions (Illumina, San Diego, CA). The Illumina reads were assembled de novo using CLC Genomics Workbench v9 (Qiagen Bioinformatics, Redwood City, CA). The WGS data of all isolates studied here can be searched and downloaded from the Sequence Read Archive (https://www.ncbi.nlm.nih.gov/sra) and Pathogen Detection System in the National Center for Biotechnology Information. The ARG were identified by the National Center for Biotechnology Information antimicrobial resistance finder process; all isolates were run against GenBank genomes in the Bacterial Antimicrobial Resistance Reference Gene Database (https://www.ncbi.nlm.nih.gov/associations/CLC) and Pathogen Detection System in the National Center for Biotechnology Information. The ARG were identified by the National Center for Biotechnology Information antimicrobial resistance finder process; all isolates were run against GenBank genomes in the Bacterial Antimicrobial Resistance Reference Gene Database (https://www.ncbi.nlm.nih.gov/associations/CLC), which included more than 5,300 sequence data for identifying bacterial genomes with AMR genes.

### RESULTS

Of the 143 *Salmonella* isolates that were investigated in this study (Tables 1–4), the highest rates of ARG were against aminoglycoside (70.63%), followed by
tetracycline (26.57%), fosfomycin (25.17%), sulfonamides (23.78%), and β-lactamases (15.38%) (Tables 1–3). The gene adaA (in 95 isolates) was the most frequently occurred ARG among the isolates, followed by gene fosA (36 isolates), tet(A) (32 isolates), and sul2 (27 isolates). The ARG against aminoglycoside were very diverse, including genes adaA, adaA1, adaA2, aac(3), aph(3′)-Ib, aph(3′)-IId, aph(3′)-II, aph(3′)-Ia, aph(3′)-Ib, aph(6)-Ic.
Table 2. Sources and antimicrobial resistance genes (ARG) of Salmonella ser. Typhimurium.

| Isolates       | Source                  | Location     | Year | ARG                                                                 |
|----------------|-------------------------|--------------|------|----------------------------------------------------------------------|
| CFSAN017093    | Duck egg yolks (Cooked, Frozen) | China        | 2010 | aph(3')-B, aph(6)-Id, ble_TEM-1, bleO, tet(A)                         |
| CFSAN017094    | Duck egg yolks (Cooked, Frozen) | China        | 2010 | aadA, aph(3')-B, aph(6)-Id, ble_TEM-1, bleO, tet(A)                  |
| CFSAN017095    | Duck egg yolks (Cooked, Frozen) | China        | 2010 | aadA, aph(3')-B, aph(6)-Id, ble_TEM-1, bleO, tet(A)                  |
| CFSAN015377    | Frozen salted duck yolk   | China        | 2002 | N/A                                                                |
| CFSAN015378    | Frozen salted duck yolk   | China        | 2002 | aadA, aph(3')-B, aph(6)-Id, ble_TEM-1, bleO, tet(A)                  |
| CFSAN015380    | Frozen salted duck yolk   | China        | 2002 | N/A                                                                |
| CFSAN013737    | Salted egg yolk          | China (Taiwan)| 2001 | sul2, tet(A)                                                       |
| CFSAN012405    | Salted duck eggs         | China (Taiwan)| 2004 | aadA                                                               |
| CFSAN015282    | Chicken jerky            | China        | 2001 | aac(3)-Ib, aadA1, tet(A), aph(3)-Ib, catA1, dfrAI2, qacEdelta1, sul1, sul2, tet(A) |
| CFSAN027862    | Chicken breast            | US:CO        | 2005 | aadA                                                               |
| CFSAN029063    | Chicken breast            | US:GA        | 2006 | aadA, ble_CMY                                                        |
| CFSAN029213    | Chicken breast            | US:MD        | 2006 | aadA, ble_CMY, sul2, tet(A)                                        |
| CFSAN029210    | Chicken breast            | US:MD        | 2006 | aadA, aph(3)-Ia, ble_CMY, sul2, tet(A)                               |
| CFSAN035417    | Chicken breast            | US:CA        | 2007 | aadA                                                               |
| CFSAN035525    | Chicken breast            | US:CT        | 2007 | aac(3), aadA1, ble_TEM-1, qacEdelta1, sul1, sul2, tet(A)            |
| CFSAN035560    | Chicken breast            | US:MD        | 2008 | aadA, ble_CMY, sul2, tet(A)                                        |
| CFSAN035575    | Chicken breast            | US:NY        | 2008 | aadA, aph(3')-Ib, aph(3)-Ia, ble_CMY, sul2, tet(A)                  |
| CFSAN036172    | Chicken breast            | US:MD        | 2008 | aadA, aph(3')-Ib, aph(6)-Id, sul2, tet(A)                           |
| CFSAN036174    | Chicken breast            | US:NM        | 2008 | N/A                                                                |
| CFSAN036179    | Chicken breast            | US:NY        | 2008 | aadA, sul2, tet(A)                                                 |
| CFSAN036177    | Chicken breast            | US:NY        | 2008 | aac(3), aph(3')-Ib, ble_CMY, sul2, tet(A)                           |
| CFSAN036183    | Chicken breast            | US:PA        | 2008 | aadA, aph(3')-Ib, aph(6)-Id, ble_CMY, tet(A), tet(B)               |
| CFSAN036186    | Chicken breast            | US:PA        | 2008 | aadA, sul2, tet(A)                                                 |
| CFSAN036257    | Chicken breast            | US:MD        | 2008 | aadA, aph(3')-Ia, sul2, tet(A)                                     |
| CFSAN036272    | Chicken breast            | US:MD        | 2008 | aadA, aph(3')-Ia, sul2, tet(A)                                     |
| CFSAN036362    | Chicken breast            | US:NY        | 2008 | aadA, aph(3')-Ia, sul2, tet(A)                                     |
| CFSAN036367    | Chicken breast            | US:NY        | 2008 | aadA, aph(3')-Ia, sul2, tet(A)                                     |
| CFSAN041824    | Chicken breast            | US:NY        | 2009 | aadA, sul2, tet(A)                                                 |
| CFSAN041835    | Chicken breast            | US:NY        | 2009 | aadA, aph(3')-Ia, ble_CMY, sul2, tet(A)                             |
| CFSAN041875    | Chicken breast            | US:PA        | 2009 | sul2, tet(A)                                                       |
| CFSAN041878    | Chicken breast            | US:PA        | 2009 | aadA, aph(3')-Ia, ble_CMY, sul2, tet(A)                             |
| CFSAN041887    | Chicken breast            | US:PA        | 2009 | aac(3), aadA, aadA1, qacEdelta1, sul1, sul2, tet(A)                |
| CFSAN040229    | Chicken breast            | US:MD        | 2009 | aadA                                                               |
| CFSAN041925    | Chicken breast            | US:CT        | 2010 | aadA, aadA2, ble_CAR-2, floR, qacEdelta1, sul1, sul1delta, tet(G)   |
| CFSAN041934    | Chicken breast            | US:GA        | 2010 | aadA, sul2, tet(A)                                                 |
| CFSAN041947    | Chicken breast            | US:MD        | 2010 | aadA, aph(3')-Ib, ble_CMY, sul2, tet(A)                             |
| CFSAN041940    | Chicken breast            | US:MD        | 2010 | aadA, ble_CMY, sul2, tet(A)                                        |
| CFSAN041965    | Chicken breast            | US:MN        | 2010 | aadA, sul2, tet(A)                                                 |
| CFSAN041987    | Chicken breast            | US:NY        | 2010 | aadA, aadA2, ble_CAR-2, floR, qacEdelta1, sul1, sul1delta, tet(G)   |
| CFSAN041662    | Chicken breast            | US:TN        | 2010 | aadA, sul2, tet(A)                                                 |

Abbreviations: CA, California; CT, Connecticut; CO, Colorado; GA, Georgia; MD, Maryland; MN, Minnesota; NM, New Mexico; NY, New York; PA, Pennsylvania; TN, Tennessee.

1No information available.
2Typhimurium var. 5.
3Typhimurium var. O:5.

and aph(6)-Id. The ARG against β-lactamases included bla, ble_CMY, ble_CMY-2, ble_TEM, ble_TEM-1, ble_OXA-1, and ble_CAR-2. The ARG of sul1, sul2, suldelta were resistant to sulfonamides. The ARG of tet(A), tet(B), tet(C), and tet(G) were resistant to tetracycline.

Among the ARG studied, Salmonella ser. Enteritidis isolates had the highest rate of aadA against aminoglycoside (streptomycin). However, we did not find ARG among the Salmonella ser. Enteritidis isolates in Salmonella ser. Enteritidis (CFSAN030067) had the β-lactamase resistant gene (bla_TEM-1). A few egg-sourced Salmonella ser. Enteritidis isolates were found to have ARG resistant to bleomycin (CFSAN024743, BleO) and quaternary ammonium compound (CFSAN057651, qacEdelta1). Only 1 egg-sourced (CFSAN024727, qnrB19) and 1 chicken-sourced (CFSAN057814, qnrB2) Salmonella ser. Enteritidis isolate were observed to have quinolone-associated ARG (Table 1). Other ARG, such as tet(A), dfrA15, dfrA25, were also found in Salmonella ser. Enteritidis isolates.

For Salmonella ser. Typhimurium, ARG against fosfomycin and quinolone were not detected in chicken-sourced isolates, and ARG against chloramphenicol, trimethoprim, and quaternary ammonium compound were not found in egg-sourced isolates (Table 4). The ARG aadA, sul2, and tet(A) were the most frequent ones contained in chicken-sourced isolates. We observed 8 and 5 different ARG against aminoglycoside and β-lactamases, respectively. Three chicken-sourced isolates carried the floR (CFSAN041925 and CFSAN041987) and catA1 (CFSAN015282) which confer resistance to
chloramphenicol. And, 5 chicken-sourced isolates contained ARG *gacEdelta1*. In addition, isolates CFSAN041925 and CFSAN041987 were the only 2 isolates contained ARG *tet(G)* among all 143 isolates (Table 2).

*Salmonella* ser. Heidelberg isolates had high rates of ARG against aminoglycoside (90%) and fosfomycin (90%) (Table 4). A total of 27 of the 30 egg-sourced isolates contained ARG against aminoglycoside (90%) and fosfomycin. And, 5 chicken-sourced isolates contained ARG against aminoglycoside (90%) and fosfomycin.

There were 3 and 2 isolates with ≥5 ARG found from *Salmonella* ser. Typhimurium (CFSAN015282, CFSAN041925, CFSAN041987) and *Salmonella* ser. Heidelberg (CFSAN036283, CFSAN035554), respectively; there was no *Salmonella* ser. Enteritidis isolate in this category (Tables 1–3). Many isolates carried 4 ARG: 17 *Salmonella* ser. Enteritidis, where chicken-sourced isolates (7) contained fewer varieties of ARG than egg-sourced isolates (13) (Table 4).

There were 3 and 2 isolates with ≥5 ARG found from *Salmonella* ser. Typhimurium (CFSAN015282, CFSAN041925, CFSAN041987) and *Salmonella* ser. Heidelberg (CFSAN036283, CFSAN035554), respectively; there was no *Salmonella* ser. Enteritidis isolate in this category (Tables 1–3). Many isolates carried 4 ARG: 17 *Salmonella* ser. Typhimurium, 4 *Salmonella* ser. Enteritidis, and 2 *Salmonella* ser. Heidelberg isolates.

**DISCUSSION**

Prevalence of antimicrobial resistant bacteria has been increasing rapidly on US meat and poultry products in recent yr (North American Meat Institute (NAMI), 2019). This study investigated ARG of 3 major *Salmonella* serotypes associated with egg and chicken sources,
using WGS data. The high rates of ARG against aminoglycosides (particularly streptomycin), tetracycline, fosfomycin, and sulfonamides among these isolates are probably related to the extensive use of these antimicrobials in the poultry industry (WHO, 2011), as well as the inappropriate use of antimicrobial agents in both livestock and humans. From 2009 to 2015, in the United States, domestic sales and distribution of antimicrobials approved for use in food-producing animals increased by 24%, and tetracycline sales represent the largest volume of these domestic sales (U.S. Food and Drug Administration (FDA), 2016). The US FDA tested 4,072 imported foods in 2000, 187 Salmonella isolates consisting of 82 serotypes were found, 60% of the resistant isolates exhibited resistance to tetracycline, 47% to sulfonamides, and 33% to streptomycin (Zhao et al., 2003). Similar results have also been reported in other countries. For example, among nontyphoidal Salmonella isolates from retail meats of the United States and China, aada1 gene was found most frequently among 6 ARG against aminoglycoside (aada1, aada2, aacC2, Kn, aph(3’)-Iba, and aac(3)-Iva) (Chen et al., 2004). The study also found other ARG, such as tet(A), tet(B), dhfr1, dhfr12, dhfr13, cat1, cat2, blatem1, and blacmy-2.

Our study only found quinolone-associated ARG in 1 egg-sourced and 1 chicken-sourced Salmonella serotypes Typhimurium and Heidelberg; all isolates from retail meats of other countries. For example, among nontyphoidal Salmonella isolates from retail meats of the United States and China, aada1 gene was detected most frequently among 6 ARG against aminoglycoside (aada1, aada2, aacC2, Kn, aph(3’)-Iba, and aac(3)-Iva) (Chen et al., 2004). The study also found other ARG, such as tet(A), tet(B), dhfr1, dhfr12, dhfr13, cat1, cat2, blatem1, and blacmy-2.

Our study only found quinolone-associated ARG in 1 egg-sourced and 1 chicken-sourced Salmonella serotypes Typhimurium and Heidelberg; all isolates from Salmonella serotypes Typhimurium and Heidelberg did not contain

### Table 4. Antimicrobial resistance genes of Salmonella.

| Antimicrobials | Egg and egg products (59) | Chicken (5) | Egg and egg products (8) | Chicken (32) | Egg and egg products (30) | Chicken (9) |
|---------------|---------------------------|-------------|--------------------------|--------------|---------------------------|-------------|
| Aminoglycoside | aadA, 26; aadA1, 1; aph(3’)-Ib, 1; aph(6)-Id, 2 | aadA, 1; aph(3’)-Ib, 1; aph(6)-Id, 1 | aadA, 4; aph(3’)-Ib, 4; aph(6)-Id, 4 | aadA, 28; aadA1, 3; aadA2, 3; aac(3), 2; aac(3)-Id, 1; aph(3’)-Ib, 7; aph(6)-Id, 4 | aadA, 27; aadA1, 3; aadA2, 3; aph(3’)-Ib, 2; aph(3’)-Ib, 6 | aadA, 1; aadA1, 1; aph(3’)-Ib, 1; aac(3), 2; aac(3)-Id, 1; aph(3’)-Ib, 7; aph(6)-Id, 4 |
| β-Lactamases | bteTEM-1, 1 | 0 | bte, 1; bteTEM-1, 3 | 0 | bteCMY-1, 10 | 0 |
| Sulfonamides | sul1, 3; sul2, 1 | sul1, 1 | sul2, 1 | sul1, 1; sul2, 2 | sul2, 12 | sul1, 3 |
| Tetracycline | tet(A), 2 | tet(A), 1 | tet(A), 5 | tet(A), 24; tet(B), 2; tet(G), 2 | 0 | tet(B), 2; tet(C), 1 |
| Fosfomycin | 0 | 0 | 0 | 0 | fosA, 27 | fosA, 9 |
| Chloramphenicol | 0 | 0 | 0 | 0 | catA1, 1 | 0 |
| Quinolone | qnrA9, 1 | qnrB2, 1 | 0 | 0 | 0 | 0 |
| Trimethoprim | dfrA15, 1; dfrA25, 1 | 0 | dfrA15, 1 | 0 | 0 | 0 |
| Bleomycin | blcO, 1 | blcO, 4 | 0 | 0 | 0 | ble, 2 |
| Quaternary ammonium compound (ethilium bromide) | qacEdeltal1, 1 | 0 | qacEdeltal5, 1 | 0 | qacEdeltal3 |

1Total number of isolates studied.
2Name of the antibiotics resistance gene, number of isolates containing the corresponding gene.

from carcasses of fattening pigs in Europe (EFSA and ECDC, 2017).

By binding to the bacterial 30S/50S ribosomal sub-unit, aminoglycosides could inhibit the translocation of the peptidyl-tRNA from A-site to P-site, causing RNA unit, aminoglycosides could inhibit the translocation of the peptidyl-tRNA from A-site to P-site, causing RNA
ARG against quinolone, although previous research showed a rise in quinolone resistance in *Salmonella* isolates associated with contaminated eggs and egg products in Europe during a 5-year survey from 2000 to 2004 (Meakins et al., 2008). The study also found a decreased occurrence of chloramphenicol and tetracyclines resistance in *Salmonella* ser. Typhimurium isolates. Our data indicated that resistance to chloramphenicol was associated with *Salmonella* ser. Typhimurium isolates from chicken origin only and fosfomycin with *Salmonella* ser. Heidelberg isolates from either egg or chicken origins. The use of different antimicrobials in different parts of the world may have contributed to this phenomenon, as well as the antimicrobial resistance variation by *Salmonella* serotypes (CDC, 2018b).

The present study also indicated that chicken-sourced isolates contained more diverse ARG than egg-sourced and egg products–sourced isolates among *Salmonella* ser. Typhimurium and *Salmonella* ser. Heidelberg. There were 5 *Salmonella* isolates from both chicken and egg sources with ARG against ≥5 antimicrobials in this study; none of them were from *Salmonella* ser. Enteritidis. Furthermore, among the isolates studied, many carried ARG against 4 antimicrobials, particularly the isolates from *Salmonella* ser. Typhimurium. Borges et al. (2017) analyzed 148 *Salmonella* ser. Enteritidis strains and found only 25 (16.9%) were susceptible to all antimicrobials tested, and poultry strains presented higher resistance and a greater number of multidrug resistance than those isolated from food involved in salmonellosis. Zhao et al. (2003) reported that 2 *Salmonella* ser. Typhimurium isolated from ground chicken exhibited resistance to 12 antibiotics among the 18 identified *Salmonella* resistant isolates from imported food in United States. In the European Union, 29.3% of human *Salmonella* isolates exhibited multidrug resistance, especially for the monophasic *Salmonella* ser. Typhimurium 1,4,[5],12:i:-, which had an extremely high rate of multidrug resistance of 81.1% (EFSA and ECDC, 2017). However, the relationship between antimicrobial resistance and multiresistance isolates from humans and animals are often confounded by the selected isolates with different serotypes, geographical locations, or temporal intervals (Carroll et al., 2017). The mechanisms of multiresistance are highly intricate. The use of different antibiotics in the life cycle of food animals make it more likely that *Salmonella* harbored by the animals might be resistant to common antibiotics, and the genes that encode these antibiotic resistances can also be transferred to human pathogens. With the increased resistance to conventional antibiotics (e.g., ampicillin and chloramphenicol), the extended-spectrum cephalosporins and fluoroquinolones were used more widely as the treatment of infections caused by multidrug-resistant *Salmonella* serotypes (Chen et al., 2004). Consequently, *Salmonella* is adapting to these drugs and developing resistance to them.

It would be great we could verify the ARG by traditional phenotypic antibiotic susceptibility testing and determine the minimum inhibitory concentrations for the antimicrobials. The information will help scientists better understand the expression or lack of expression of these ARG. However our WGS data were accumulated in a few years, we could not locate all the isolates anymore. This topic is worth future study as it is important to prove the correlation between the genotypic and phenotypic resistances. It has practical implications for developing prevention and control strategies for antimicrobial resistant bacteria.

In summary, among the 143 *Salmonella* isolates studied, high rates of ARG against aminoglycoside (particularly streptomycin), tetracycline, fosfomycin, sulfonamides, and β-lactamases were observed; *Salmonella* ser. Typhimurium isolates contained more variety of ARG and higher level of multiresistance than *Salmonella* ser. Enteritidis and *Salmonella* ser. Heidelberg; Chicken-sourced isolates contained more different types of ARGs than egg-sourced and egg products–sourced isolates among *Salmonella* ser. Typhimurium and *Salmonella* ser. Heidelberg. Widespread *Salmonella* antimicrobial-resistant isolates sourced from egg and chicken underline the urgent need for continued both consumer and workers/farmers education and efforts on proper animal raising and food handling/cooking to decrease/eradicate *Salmonella* in poultry and egg products. This also demonstrates the importance of One Health Initiative, which is a collaborative, multisectoral, and interdisciplinary approach, recognizing the interconnection among animals, plants, people, and their shared environment, with the collaboration at the local, regional, national, and global levels, to achieve optimal health outcomes (https://www.cdc.gov/onehealth/index.html).

**DISCLOSURES**

The authors declare no conflicts of interest. Mention of trade names or commercial products in the article is solely for the purpose of providing scientific information and does not imply recommendation or endorsement by the US Food and Drug Administration.

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