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# High levels of antimicrobial resistance in *Escherichia coli* and *Salmonella* from poultry in Ecuador

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**ABSTRACT**

**Objective.** To describe antimicrobial resistance profiles of *Escherichia coli* and *Salmonella* spp. isolated from chicken carcasses and the antimicrobials commonly used in animals in Ecuador and provide information on antimicrobial resistance patterns for implementing evidence-based corrective measures.

**Methods.** Meat samples were collected from chicken carcasses in 199 slaughterhouses across Ecuador as part of a national pilot study for monitoring antimicrobial resistance in agricultural sources in 2019. Samples were tested for *E. coli* and *Salmonella* spp. Sensitivity to 10 critically important and three highly important antimicrobials (from a human health perspective) was assessed. The country report submitted to the World Organization for Animal Health was accessed to extract the quantity of antimicrobials produced or imported for use in animals.

**Results.** Of 383 samples, *E. coli* was isolated from 148 (39%) and *Salmonella* spp. from 20 (5%) samples. Ninety percent of the isolates were resistant to at least one critically important antimicrobial. Resistance was highest to erythromycin (*E. coli* 76%; *Salmonella* spp. 85%) and tetracycline (*E. coli* 71%; *Salmonella* spp. 90%). Critically or highly important antimicrobials (colistin, tetracycline, trimethoprim/sulfamethoxazole) formed the bulk (87%) of antimicrobials used in animals as per the World Organization for Animal Health report.

**Conclusions.** High prevalence of antimicrobial resistance in poultry in Ecuador calls for the development of guidelines and regulations on the use of antimicrobials and for engagement with livestock producers. The existing surveillance system needs to be strengthened to improve the monitoring of antimicrobial use and evolving resistance patterns.

**Keywords** Microbial sensitivity tests; drug resistance, microbial; beta-lactamases; poultry; operations research; Ecuador.

The World Health Organization (WHO) recognizes antimicrobial resistance (AMR) as one of the most important threats to health in the 21st century, citing the misuse and overuse of antimicrobial products in human and veterinary medicine and food production as primary drivers of drug resistance globally (1). Estimates of the number of antibiotics used in agriculture worldwide range from 63 000 to 240 000 tons per year; the considerable uncertainty in these estimates is mainly due to poor surveillance and data collection in many countries (2).

Poultry farms are considered major contributors to AMR because of their extensive use of antimicrobial products, which are used as both growth promoters and prophylactic treatment against bacterial infections in the birds as they are raised (3). Indeed, the presence of antibiotic residues and resistant bacteria in animal urine and stool often combine with farms' suboptimal waste management and the use of fecal matter as fertilizer to amplify the spread of resistant genes and the selection of resistant bacteria in the environment (1). WHO recommends

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testing for *Escherichia coli* and *Salmonella* spp. in chicken samples as part of the integrated AMR surveillance in poultry farms initiative (1).

In Latin America, there are several reports on AMR among animals for human consumption; however, the interaction between AMR and antimicrobial use in food production has not been well documented (4). Nevertheless, a series of small studies looking into various animal production systems in Ecuador have reported colistin- and multidrug-resistant *E. coli*, *Salmonella* spp., and *Campylobacter* (5–7); and multidrug-resistant strains of *E. coli* have also been found in river water in the capital city of Quito, which possibly indicates that epidemiologically important resistance is being transmitted at sites where humans and animals interact with the environment (8).

In response to the rising AMR threat, Ecuador has taken significant steps to address the problem: a five-year national plan to prevent and control AMR was established by ministerial decree in 2019. Key objectives of the decree were to design and implement a national surveillance system for AMR in all areas (human, animal, and environment) and to monitor antimicrobial use in animals (9). The Ecuadorian Ministry of Agriculture and Livestock also prohibited the production, importation, trade, and use of products containing colistin in animals in 2019 (10).

In Ecuador, chicken is widely consumed and the population's average poultry consumption per capita is high (26 kg per year) compared to the world average (16 kg per year) (11, 12). The massive scale of the poultry industry in Ecuador makes it a potentially significant source of AMR. Although several studies have shown that poultry-related AMR may be important in Ecuador, the extent of the problem on a national level is unknown (6, 7, 13).

To address this gap, the Ministry of Agriculture and Livestock conducted a study of bacteria isolated from poultry carcasses in a nationwide sample of slaughterhouses in Ecuador in 2019. The aim was to describe AMR profiles of *E. coli* and *Salmonella* spp. isolated from chicken carcasses and the antimicrobials commonly used in animals in Ecuador.

This study provides baseline data on antimicrobial use and resistance in animal production systems to inform surveillance activities and animal health policies and programs in Ecuador and the wider Latin American region.

## MATERIALS AND METHODS

### Study design and setting

This is a cross-sectional study using data collected by Agrocalidad, the regulatory and control agency for animal and plant health in Ecuador.[1]

Ecuador has a population of approximately 17 million and is divided into 24 provinces, which can be grouped under three regions: the Amazon basin, the Andean highlands, and the coastal region. Poultry production is one of Ecuador's most important industries: in 2019, all farms together produced around 281 million chickens. The industry is concentrated in the provinces of Guayas, Santo Domingo, and Pichincha and supplies nearly the entire national demand (11). There are 546 registered public and private slaughterhouses in the country. Slaughterhouses are regulated by Agrocalidad, which is part of the Ministry of Agriculture and Livestock, one of the three ministries involved in the implementation of the National Plan for the Prevention and Control of AMR (9). Since 2019, antimicrobial use in animals has been monitored and reported to the World Organization for Animal Health (WOAH).

### Study period

The samples from the slaughterhouses were collected between 14 May and 28 November 2019. Each slaughterhouse was visited once. Laboratory investigations were carried out over the course of 2019 and 2020. Data on antimicrobials produced or imported for use in animals in 2019 were collected in 2020.

### Study population and sampling

Raw chicken meat samples were obtained from healthy animals that had just been slaughtered, before the meat was processed. At the time the pilot study was designed, the frequency of *E. coli* and *Salmonella* spp. in such samples was unknown at a national level. For the sample size calculation, the anticipated prevalence of meat samples with bacterial isolates was set at 50% and the desired absolute precision at 5%. This yielded a target sample size of 384 poultry carcasses.

Probability proportionate to size was used to select slaughterhouses and samples to be included. First, the provinces of Ecuador were ranked according to the number of chickens slaughtered per month in 2018. The target number of slaughterhouses and samples to be included per province was determined so that it was proportional to the number of chickens slaughtered. Next, provincial food safety technical officers organized the sampling as part of their routine monitoring visits to slaughterhouses until they reached the target number of samples for their province.

### *E. coli* and *Salmonella* spp. isolation and antimicrobial susceptibility testing

All microbiological analyses for this study were done at one laboratory in Quito. This central laboratory is part of the Ministry of Agriculture and Livestock (accreditation ISO/IEC 17025 and 9001). The samples were accompanied by certificates containing information about origin, storage, and transport conditions according to the recommendations of the Ecuadorian technical standards (14). If any irregularities were detected by the technician at the central laboratory, the corresponding sample was excluded.

The included samples were processed and cultured on selective media following standard operating procedures. The colonies obtained were first examined using a Gram stain; next, the presence of *E. coli* and *Salmonella* spp. was confirmed through biochemical testing. For antimicrobial susceptibility testing (AST), the Kirby Bauer method, double disk test (for confirmation of extended-spectrum beta-lactamase-producing strains), and the broth microdilution test (for colistin) were used. AST was interpreted in line with the Clinical and Laboratory Standards Institute (CLSI) Guidelines (15).

[1] The dataset used in this article can be made available, on request, by the corresponding author.

AST was conducted for 13 antibiotics: gentamicin, chloramphenicol, ceftriaxone, erythromycin, ampicillin, amoxicillin, amoxicillin/clavulanic acid, ampicillin/sulbactam, ciprofloxacin, trimethoprim/sulfamethoxazole, meropenem, tetracycline, and colistin. These drugs were chosen because are part of the National Plan for Surveillance and Control of Contaminants in Primary Production (16).

### Data on antimicrobial use in animals

Agrocalidad regulates the registration, control, marketing, and use of veterinary products. Via an online platform, manufacturers and distributors declare product name, class, and amount in kg of antimicrobial agents used in animals for human consumption according to type of use: veterinary medical use (including prevention), growth promotion, or both (17). For the purpose of this study, we obtained the number of antimicrobials imported or produced (in kg) in Ecuador during 2019 from the report sent by Agrocalidad to WHOA in 2020.

### Statistical analysis

*E. coli* and *Salmonella* spp. resistance patterns and amount of antimicrobials imported/produced (in kg) in Ecuador were summarized using descriptive statistics (counts, proportions, and sums) and presented according to the WHO classification of antimicrobial importance for human medicine (18). To compare proportions across regions (coastal, Andean highlands, Amazon basin), we used chi-square testing with a level of significance set at $p \leq 0.05$.

### Ethics

Ethics approval was obtained from the Ethics Committee of the Society for the Fight against Cancer (SOLCA) in Ecuador, the Ethics Committee of the Pan American Health Organization (PAHOERC), and The Union Ethics Advisory Group of the International Union against Tuberculosis and Lung Disease, Paris, France.

## RESULTS

### AMR profiles of *E. coli* and *Salmonella* spp. isolated from chicken carcasses

In this study, chicken meat samples were obtained from 199 slaughterhouses across 20 provinces of Ecuador. Among 383 raw chicken meat samples cultured in selective media, *E. coli* was isolated from 148 (39%) samples, *Salmonella* spp. from 20 (5%) samples, and 7 (4%) samples were positive for both bacteria (Figure 1).

All the isolates underwent AST for 10 critically important and three highly important antimicrobials (per the WHO classification). Approximately 90% of the *E. coli* and *Salmonella* spp. isolates were resistant to at least one of the antimicrobials considered critically important for human use (Figure 1). The 13 antibiotics tested belonged to 10 classes of antibiotics (2 penicillins and 2 beta lactams). Resistance to three or more classes of antibiotics was considered as multidrug resistance. Among 148 *E. coli* isolates, 100 (68%) had multidrug resistance. Among 20 *Salmonella* spp. isolates, 15 (75%) had multidrug resistance.

Among isolates with *E. coli*, resistance to erythromycin was highest 112 (76%) followed by tetracycline 105 (71%). Nearly half of the isolates were resistant to trimethoprim/sulphamethoxazole (84; 57%), penicillins (71; 48%), or ciprofloxacin (57; 39%). All *E. coli* isolates were susceptible to carbapenems (Table 1). Extended-spectrum beta-lactamases (ESBL) were detected in 32 (22%) of *E. coli* isolates.

Among isolates of *Salmonella* spp., resistance to tetracycline was the highest (18; 90%), followed by erythromycin (17; 85%) and ceftriaxone (16; 80%). While 15 (75%) of the isolates were resistant to penicillins without inhibitors, all *Salmonella* spp. isolates were susceptible to penicillins with inhibitors and 16 (80%) were intermediate to ciprofloxacin. No resistance was observed against colistin and carbapenems (Table 1). ESBL were detected in 8 (40%) of the *Salmonella* spp. isolates.

Slaughterhouses in the coastal region contributed most of the samples (246 of 383 samples). Resistance rates among *E. coli* and *Salmonella* spp. isolates were similar across all regions of the country, except for the Amazon region, where *Salmonella* spp. were not recovered, as shown in Table 2. Details of resistance rates within different provinces in each region are shown in Table 3 and 4.

### Antimicrobial use in animals raised for human consumption

According to data reported to the WOAH, 134 148 kg of antimicrobials were imported or produced for use in animals (growth promotion, medical use, or both) in Ecuador in 2019. Antimicrobials of the critically important (40%) and highly important group (47%) constituted the bulk of these antimicrobials. Tetracycline and colistin were imported in larger quantities compared to the rest of the antimicrobials (Table 5).

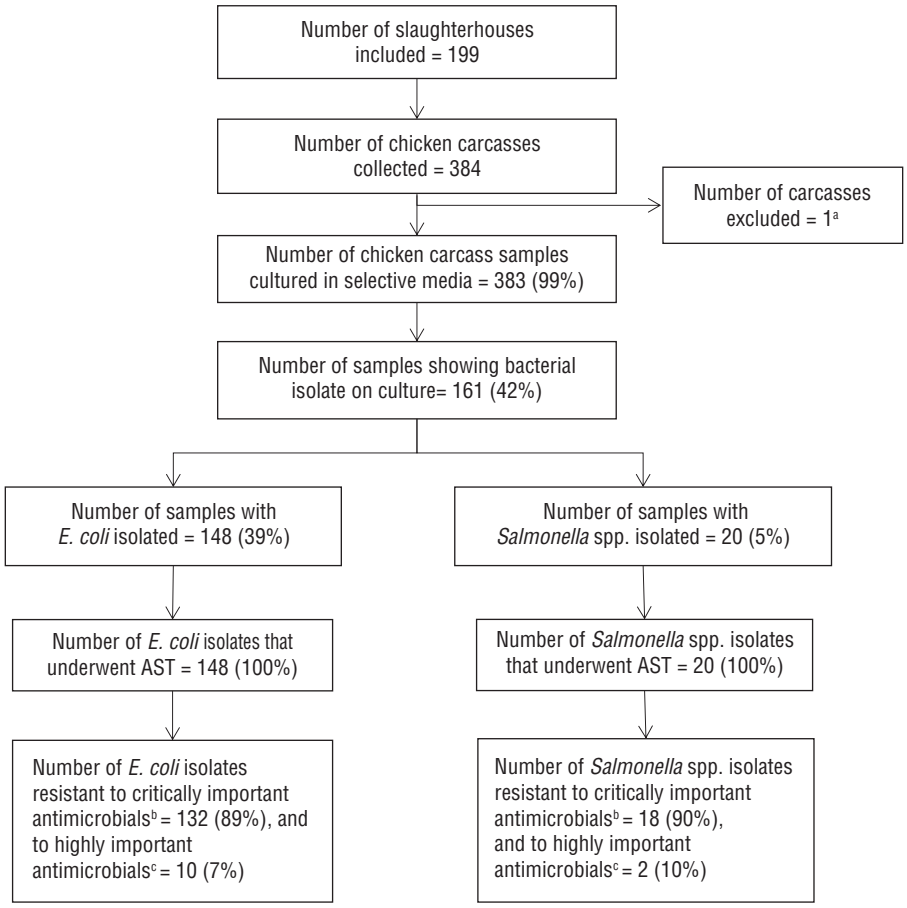
Colistin, a critically important antimicrobial, was used mainly for growth promotion (82%). The rest of the critically imported antimicrobials (ciprofloxacin, erythromycin, gentamicin, and ampicillin) and all the highly important antimicrobials (tetracycline, trimethoprim/sulphamethoxazole, and chloramphenicol) were used for veterinary medical purposes primarily (Table 5).

## DISCUSSION

This is the first nationwide study reporting on AMR in the poultry production system of Ecuador, conducted as part of Agrocalidad's integrated national program for monitoring AMR (19). Nine in ten isolates of *E. coli* and *Salmonella* spp. cultured from chicken carcasses sampled from slaughterhouses were resistant to an antimicrobial considered critically important for human health. The findings of this study are important, as they could serve as evidence to inform efforts around antimicrobial stewardship in the animal production industry of Ecuador.

The prevalence of *E. coli* (39%) and *Salmonella* spp. (5%) was lower compared to other studies undertaken in Ecuador and other Latin American countries (5, 20). The prevalence of *E. coli* in chicken meat samples has been reported to be around 60%–73% and that of *Salmonella* around 20%–30% in other studies from this region (5, 20). The prevalence of serovars of *Salmonella* spp. was not analyzed. In Ecuador, the most common serotype reported in poultry production systems is *S. infantis* (83%) (21).

**FIGURE 1. Sample collection, isolation of *E. coli* and *Salmonella* spp., and resistance to antimicrobials among chicken carcasses collected from slaughterhouses across 20 provinces, Ecuador, 2019**




***Notes***: AST, antimicrobial susceptibility test.
[a] Excluded due to non-compliance with standard operating procedures for sample storage at the laboratory.
[b] Critically important antimicrobials: ampicillin, ampicillin/sulbactam, amoxicillin, amoxicillin/clavulanic acid, ceftriaxone, ciprofloxacin, colistin, erythromycin, gentamicin, and meropenem.
[c] Highly important antimicrobials: sulphamethoxazole/trimethoprim, tetracycline, and chloramphenicol.
***Source*:** Prepared by the authors based on the study results.

In this study, samples were taken after disinfecting the raw chicken meat in slaughterhouses with hyperchlorinated water. This could be a possible cause of the low prevalence rates. There is a need to evaluate and standardize the procedures for sampling and culture to assure comparability of the data.

Isolates of both bacteria (*E. coli* and *Salmonella* spp.) showed high rates of resistance to critically important antimicrobials. More than 80% of the samples showed resistance to tetracycline and erythromycin. Studies on AMR profiles of poultry meat in Latin America have reported varying resistance patterns among *E. coli* and *Salmonella* isolates (6, 13, 22–24). Differences in geographical contexts and methods used for sample processing could be the reason for this variation.

We found extremely high rates of resistance to critically important antimicrobials in the meat samples. These drugs are the sole or one of limited available therapies to treat serious bacterial infections in humans. Although this is a cause of concern, we believe that this merits further investigation. A few pathways of inquiry that future research can pursue to evaluate the true implications of these findings for human health include but are not limited to (i) establishing the provenance of this AMR, (ii) assessing its relationship with humans through molecular studies, and (iii) evaluating whether the resistant bacteria found in unprocessed meat are retained in the processed or cooked forms that are actually consumed by humans.

Some of these antimicrobials, like tetracycline, are also the mainstay for treating common veterinary infections. Tetracycline was the antibiotic imported for veterinary medical use in the largest quantity by Ecuador in 2019, as per the WOAH report. The possibility of misuse of these antimicrobials in the animal production sectors, thus leading to AMR, cannot be ruled out and must be investigated. There is an urgent need to develop standard guidelines for the rational use of antimicrobials in animals and to put in place mechanisms to ensure strict adherence to these guidelines.

Resistance to critically important antimicrobials was uniformly high (approximately 90%) in all regions of Ecuador, including those with low poultry production such as the Amazon basin. As the poultry industry continues to expand in the country, now is the right time to take measures to promote judicious use of antimicrobials in these regions. This can be done

**TABLE 1. Antimicrobial susceptibility profile of *E. coli and Salmonella* spp. isolated from chicken carcasses collected from slaughterhouses across 20 provinces of Ecuador, 2019**

| Antimicrobial agent | *E. coli* isolates (*N* = 148) | | | | | | *Salmonella* spp. isolates (*N* = 20) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Susceptible | | Intermediate | | Resistant | | Susceptible | | Intermediate | | Resistant | |
| | *n* | (%)[a] | *n* | (%)[a] | *n* | (%)[a] | *n* | (%)[b] | *n* | (%)[b] | *n* | (%)[b] |
| Erythromycin[c] | 0 | (0) | 36 | (24) | 112 | (76) | 0 | (0) | 3 | (15) | 17 | (85) |
| Tetracycline[d] | 38 | (26) | 5 | (3) | 105 | (71) | 2 | (10) | 0 | (0) | 18 | (90) |
| Trimethoprim/sulphamethoxazole[d] | 64 | (43) | 0 | (0) | 84 | (57) | 6 | (30) | 0 | (0) | 14 | (70) |
| Ampicillin[c] | 67 | (45) | 7 | (5) | 74 | (50) | 5 | (25) | 0 | (0) | 15 | (75) |
| Amoxicillin[c] | 76 | (51) | 3 | (2) | 69 | (47) | 5 | (25) | 0 | (0) | 15 | (75) |
| Ciprofloxacin[c] | 71 | (48) | 20 | (14) | 57 | (39) | 4 | (20) | 16 | (80) | 0 | (0) |
| Chloramphenicol[d] | 87 | (59) | 8 | (5) | 53 | (36) | 10 | (50) | 0 | (0) | 10 | (50) |
| Ceftriaxone[c] | 107 | (72) | 10 | (7) | 31 | (21) | 4 | (20) | 0 | (0) | 16 | (80) |
| Gentamicin[c] | 122 | (82) | 9 | (6) | 17 | (12) | 7 | (35) | 3 | (1) | 10 | (50) |
| Amoxicillin/clavulanic acid[c] | 136 | (92) | 4 | (3) | 8 | (5) | 20 | (100) | 0 | (0) | 0 | (0) |
| Ampicillin/sulbactam[c] | 132 | (89) | 11 | (7) | 5 | (3) | 20 | (100) | 0 | (0) | 0 | (0) |
| Colistin[c] | 144 | (97) | 0 | (0) | 4 | (3) | 20 | (100) | 0 | (0) | 0 | (0) |
| Meropenem[c] | 148 | (100) | 0 | (0) | 0 | (0) | 20 | (100) | 0 | (0) | 0 | (0) |

***Notes:***
[a] Percentage calculated using the total number of *E. coli* (148) isolates as denominator.
[b] Percentage calculated with the total number of *Salmonella* spp. (20) isolates as denominator.
[c] Critically important antimicrobials for human use.
[d] Highly important antimicrobials for human use.
***Source:*** Prepared by the authors based on the study results.

**TABLE 2. Regional distribution of culture results and antimicrobial resistance patterns in meat samples from chicken carcasses collected from slaughterhouses of Ecuador, 2019**

| Region | Total carcasses sampled | *E. coli* | | | | *Salmonella* spp. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total isolates | | Resistance to CI antimicrobials | | Total isolates | | Resistance to CI antimicrobials | |
| | | *n* | (%)[a] | *n* | (%)[b] | *n* | (%)[a] | *n* | (%)[b] |
| **All regions** | 383 | 148 | (39) | 132 | (89) | 20 | (5) | 18 | (90) |
| **Andean highlands** | 133 | 52 | (39) | 45 | (87) | 12 | (9) | 11 | (92) |
| **Coast** | 246 | 93 | (39) | 84 | (90) | 8 | (3) | 7 | (88) |
| **Amazon basin** | 4 | 3 | (75) | 3 | (100) | 0 | (0) | 0 | 0 |
| ***p*-value[c]** | | 0.552 | | 0.967 | | 0.102 | | 0.707 | |

***Notes:*** CI, critically important for human use as per the World Health Organization classification.
[a] Percentage calculated with the total number of carcasses sampled as denominator.
[b] Percentage calculated with total number of samples with isolates as denominator.
[c] *p*-value derived from chi-square test.
***Source:*** Prepared by the authors based on the study results.

by sensitizing livestock producers to the dangers of AMR and engaging them regarding rational use of these drugs.

No resistance was found to ciprofloxacin in *Salmonella* spp., one of the most commonly used antibiotics in poultry production. This is contrary to findings from other studies conducted on poultry in Ecuador, which have reported resistance rates to ciprofloxacin ranging from 64% in meat samples to as high as 99% in cecal samples (13, 21). There is a need to review the procedure of the disc diffusion method used to evaluate antimicrobial sensitivity patterns of ciprofloxacin in this study.

We assessed the association between the resistance patterns found in this study and the antimicrobials that are commonly used in animals in Ecuador. While the resistance to tetracycline and erythromycin was higher in the isolates from chicken carcasses, colistin, tetracycline, and trimethoprim/sulfamethoxazole formed the bulk of antimicrobials used in animals as per the WOAH report on antimicrobial use in animals raised for human consumption (2019). It is pertinent to note that while the isolates were all obtained from poultry, the WOAH report includes antimicrobial use in the animal production sectors as a whole. Therefore, it is not possible to attribute AMR found in this study to high levels of use of any particular antimicrobial. As a next step, antimicrobial use in different animal production industries can be monitored in actual field settings and then triangulated with data on local AMR patterns.

The WOAH report also showed that colistin was the antibiotic mostly commonly used for growth promotion. There are several reports in Ecuador and Latin America about dissemination and high levels of colistin resistance in human, animals, and the environment (25, 26). Consequently, in 2019 Agrocalidad issued a ban on the use of this antibiotic in animals in Ecuador (27). Resistance to colistin was found to be low (2.7%) in this study. However, in view of the reports of resistance from other studies and the prevailing ban, it is important to closely regulate the use of this critically important antimicrobial and to monitor the emergence of resistance through continuous surveillance.

**TABLE 3. Culture results and antimicrobial resistance patterns of *E. coli* in meat samples from chicken carcasses collected from slaughterhouses of Ecuador, by province, 2019**

| Province | *E. coli* isolated | | | |
|---|---|---|---|---|
| | Total isolates | | Isolates with resistance to CI antimicrobials | |
| | *n* | (%)[a] | *n* | (%)[b] |
| **Coastal region** | **88** | **(38)** | **79** | **(90)** |
| Los Ríos | 4 | (67) | 4 | (100) |
| Guayas | 71 | (46) | 65 | (92) |
| Santo Domingo | 14 | (21) | 11 | (79) |
| Santa Elena | 1 | (33) | 1 | (100) |
| Azuay | 1 | (20) | 1 | (100) |
| Manabí | 1 | (14) | 1 | (100) |
| El Oro | 0 | (0) | 0 | (0) |
| **Andean highlands region** | **53** | **(41)** | **46** | **(87)** |
| Bolívar | 1 | (100) | 1 | (100) |
| Tungurahua | 3 | (50) | 3 | (100) |
| Imbabura | 11 | (44) | 11 | (100) |
| Chimborazo | 2 | (40) | 0 | (0) |
| Cotopaxi | 4 | (40) | 3 | (75) |
| Pichincha | 30 | (39) | 26 | (87) |
| Loja | 2 | (33) | 2 | (100) |
| **Amazon basin region** | **3** | **(30)** | **3** | **(0)** |
| Morona | 1 | (100) | 1 | (100) |
| Napo | 1 | (100) | 1 | (100) |
| Pastaza | 1 | (50) | 1 | (100) |
| Orellana | 0 | (0) | 0 | (0) |
| Sucumbíos | 0 | (0) | 0 | (0) |
| Zamora | 0 | (0) | 0 | (0) |
| **Total** | **144** | **(39)** | **128** | **(90)** |

***Notes:*** CI, critically important for human use per WHO classification.
[a] Percentage calculated with total number of carcasses sampled as denominator.
[b] Percentage calculated with total number of samples with isolates as denominator.
***Source:*** Prepared by the authors based on the study results.

**TABLE 4. Culture results and antimicrobial resistance patterns of *Salmonella* spp. in meat samples from chicken carcasses collected from slaughterhouses of Ecuador, by province, 2019**

| Province | *Salmonella* spp. isolated | | | |
|---|---|---|---|---|
| | Total isolates | | Isolates with resistance to CI antimicrobials | |
| | *n* | (%)[a] | *n* | (%)[b] |
| **Coastal region** | **8** | **(3)** | **7** | **(88)** |
| Los Ríos | 0 | (0) | 0 | (0) |
| Guayas | 3 | (2) | 3 | (100) |
| Santo Domingo | 5 | (8) | 4 | (80) |
| Santa Elena | 0 | (0) | 0 | (0) |
| Azuay | 0 | (0) | 0 | (0) |
| Manabí | 0 | (0) | 0 | (0) |
| El Oro | 0 | (0) | 0 | (0) |
| **Andean highlands region** | **12** | **(9)** | **11** | **(92)** |
| Bolívar | 0 | (0) | 0 | (0) |
| Tungurahua | 0 | (0) | 0 | (0) |
| Imbabura | 3 | (12) | 3 | (100) |
| Chimborazo | 0 | (0) | 0 | (0) |
| Cotopaxi | 0 | (0) | 0 | (0) |
| Pichincha | 8 | (10) | 7 | (88) |
| Loja | 1 | (17) | 1 | (100) |
| **Amazon basin region** | **0** | **(0)** | **0** | **(0)** |
| Morona | 0 | (0) | 0 | (0) |
| Napo | 0 | (0) | 0 | (0) |
| Pastaza | 0 | (0) | 0 | (0) |
| Orellana | 0 | (0) | 0 | (0) |
| Sucumbíos | 0 | (0) | 0 | (0) |
| Zamora | 0 | (0) | 0 | (0) |
| **Total** | **20** | **(5)** | **18** | **(90)** |

***Notes:*** CI, critically important for human use per WHO classification.
[a] Percentage calculated with total number of carcasses sampled as denominator.
[b] Percentage calculated with total number of samples with isolates as denominator.
***Source:*** Prepared by the authors based on the study results.

To the best of our knowledge, this is the first study from Ecuador that reports on AMR in the poultry industry from a sample of slaughterhouses across the country. The study also has certain limitations. There were limitations in the procedures for sample collection and AST used in this study, which may have influenced the resistance rates reported here. AST was conducted for a panel of 13 antibiotics that were considered important in the Ecuadorian context. Therefore, we are not able to comment on resistance to other antimicrobials that may be of importance from a human health perspective. It is advisable to include a wider range of antibiotics in future studies.

In conclusion, the high rates of AMR in the poultry industry calls for Agrocalidad to strengthen the existing surveillance program in order to improve the monitoring of antimicrobial use in animals and evolving resistance patterns in the country. Policies need to be developed to regulate the use of antimicrobials of critical or high importance in human health. This study also paves the way for future research studies that can help to better understand the implications of the AMR reported in this study for human health.

**Author contributions.** GV, YC, FP, and KV contributed to the conception and design of the study. GV collected the data. JI, MF, and KRV contributed to the design of sampling, laboratory analysis and interpretation. PT and DN did the data analysis and interpretation. GV and YC drafted the manuscript. PT, DN, FP, and KV contributed to the critical review and revision of the manuscript. All authors reviewed and approved the final version.

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**TABLE 5. Antimicrobials used in animals raised for human consumption, classified by importance for human health (WHO classification), Ecuador, 2019**

| Pharmacological subgroup | Antimicrobial agent | Amount imported or produced (in kg) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Total | For veterinary medical use and growth promotion[a] | | For veterinary medical use[a] | | For growth promotion[a] | |
| | | Amount[b] (%) | Amount | (%)[c] | Amount | (%)[c] | Amount | (%)[c] |
| **Critically important antimicrobials** | | **54 176 (40)** | **2 518** | **(5)** | **26 639** | **(49)** | **24 100** | **(45)** |
| Polypeptides | Colistin | 29 295 | 0 | (0) | 5 195 | (18) | 24 100 | (82) |
| Fluoroquinolones | Ciprofloxacin | 10 721 | 1 604 | (15) | 9 117 | (85) | 0 | (0) |
| Macrolides | Erythromycin | 7 248 | 664 | (9) | 6 584 | (87) | 0 | (0) |
| Aminoglycosides | Gentamicin | 2 903 | 109 | (4) | 2 794 | (96) | 0 | (0) |
| Penicillins | Ampicillin and/or amoxicillin[d] | 2 852 | 0 | (0) | 2 852 | (100) | 0 | (0) |
| 3rd and 4th generation cephalosporins | Ceftriaxone | 9 | 0 | (0) | 9 | (100) | 0 | (0) |
| Others | Fosfomycin | 740[d] | 140 | (19) | 88 | (12) | 0 | (0) |
| **Highly important antimicrobials** | | **63 431 (47)** | **1 674** | **(3)** | **61 646** | **(97)** | **35** | **(0.1)** |
| Sulfonamides | Trimethoprim/ sulphamethoxazole | 11 218 | 68 | (1) | 11 149 | (99) | 0 | (0) |
| Tetracyclines | Tetracycline | 46 909 | 773 | (2) | 46 117 | (98) | 0 | (0) |
| Amphenicols | Chloramphenicol | 3 622 | 724 | (20) | 2 843 | (80) | 0 | (0) |
| Lincosamides | Lincomycin | 1 682 | 109 | (7) | 1 537 | (91) | 35 | (2) |
| **Important antimicrobials** | | **8 362 (6)** | **0** | **(0)** | **8 006** | **(96)** | **0** | **(0)** |
| Pleuromutilins | Tiamulin | 8 362 | 0 | (0) | 8 006 | (96) | 0 | (0) |

***Notes:***
[a] Ecuadorian routine reporting formats recorded the purpose of antimicrobial use as (i) veterinary medical use and growth promotion, (ii) veterinary medical use, or (iii) growth promotion.
[b] The total amount as per report is shown here; this does not match the total of the three types of use because data on use were incomplete in the report.
[c] Percentage calculated with total amount as the denominator.
[d] Includes ampicillin, ampicillin/sulbactam, amoxicillin, and amoxicillin/clavulanic acid.
***Source:*** Prepared by the authors based on the study results.

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## Niveles elevados de resistencia antimicrobiana de las bacterias *Escherichia coli* y *Salmonella* en aves de corral en Ecuador

**RESUMEN**

**Objetivo.** Describir los perfiles de resistencia antimicrobiana de las bacterias *Escherichia coli* y *Salmonella* spp. aisladas en carne de pollo y los antimicrobianos comúnmente empleados en animales en Ecuador, así como proporcionar información sobre los patrones de resistencia a los antimicrobianos para poner en marcha medidas correctivas basadas en la evidencia.

**Métodos.** Se recogieron muestras de carne de pollo en 199 mataderos de todo Ecuador en el marco de un estudio piloto nacional para monitorear la resistencia a los antimicrobianos en fuentes agrícolas en el 2019. Se analizaron las muestras en busca de *E. coli* y *Salmonella* spp. Se evaluó la sensibilidad a diez antimicrobianos de importancia crítica y tres muy importantes (para la salud humana). Se accedió al informe de país presentado ante la Organización Mundial de Sanidad Animal para obtener la cantidad de antimicrobianos producidos o importados para su uso en animales.

**Resultados.** De 383 muestras, se aisló *E. coli* en 148 (39%) y *Salmonella* spp. en 20 (5%). En total, 90% de las cepas aisladas fueron resistentes a al menos un antimicrobiano de importancia crítica. Hubo una mayor resistencia a la eritromicina (*E. coli:* 76%; *Salmonella* spp.: 85%) y a la tetraciclina (*E. coli*: 71%; *Salmonella* spp.: 90%). Los antimicrobianos de importancia crítica o muy importantes (colistina, tetraciclina, trimetoprima/sulfametoxazol) constituyeron la mayor parte (87%) de los antimicrobianos empleados en animales según el informe de la Organización Mundial de Sanidad Animal.

**Conclusiones.** Debido a la alta prevalencia de la resistencia a los antimicrobianos en las aves de corral en Ecuador, son imprescindibles la elaboración de directrices y regulaciones sobre el uso de antimicrobianos y el compromiso con los productores pecuarios. Es necesario fortalecer el sistema de vigilancia existente para mejorar el seguimiento del uso de antimicrobianos y de la evolución de los patrones de resistencia.

**Palabras clave** Pruebas de sensibilidad microbiana; farmacorresistencia microbiana; beta-lactamasas; aves de corral; investigación operativa; Ecuador.

## Altos níveis de resistência aos antimicrobianos em *Escherichia coli* e *Salmonella* de aves de criação no Equador

**RESUMO**

**Objetivo.** Descrever perfis de resistência aos antimicrobianos em *Escherichia coli* e *Salmonella* spp. isoladas de carcaças de frango e os antimicrobianos comumente usados em animais no Equador e fornecer informações sobre padrões de resistência aos antimicrobianos para implementar medidas corretivas baseadas em evidências.

**Métodos.** Foram coletadas amostras de carne de carcaças de frango em 199 abatedouros em todo o Equador como parte de um estudo piloto nacional para monitorar a resistência aos antimicrobianos de origem agrícola em 2019. Foram testadas amostras de *E. coli* e *Salmonella* spp. Foi avaliada a sensibilidade a 10 agentes antimicrobianos de importância crítica e três agentes antimicrobianos muito importantes (do ponto de vista da saúde humana). O relatório do país apresentado à Organização Mundial de Saúde Animal foi acessado para extrair a quantidade de antimicrobianos produzidos ou importados para uso em animais.

**Resultados.** De 383 amostras, *E. coli* foi isolada em 148 (39%) e *Salmonella* spp. em 20 (5%). Noventa por cento dos isolados foram resistentes a pelo menos um antimicrobiano de importância crítica. A resistência foi maior à eritromicina (*E. coli*, 76%; *Salmonella* spp., 85%) e à tetraciclina (*E. coli*, 71%; *Salmonella* spp., 90%). Antimicrobianos de importância crítica ou muito importantes (colistina, tetraciclina, trimetoprim/sulfametoxazol) responderam pela maior parte (87%) dos antimicrobianos utilizados em animais, conforme o relatório da Organização Mundial de Saúde Animal.

**Conclusões.** A alta prevalência de resistência aos antimicrobianos na avicultura no Equador exige o desenvolvimento de diretrizes e regulamentos sobre o uso de antimicrobianos e o envolvimento com os produtores de gado e avícolas. O sistema de vigilância existente precisa ser reforçado para melhorar o monitoramento do uso de antimicrobianos e a evolução dos padrões de resistência.

**Palavras-chave** Testes de sensibilidade microbiana; resistência microbiana a medicamentos; beta-lactamases; aves domésticas; pesquisa operacional; Equador.